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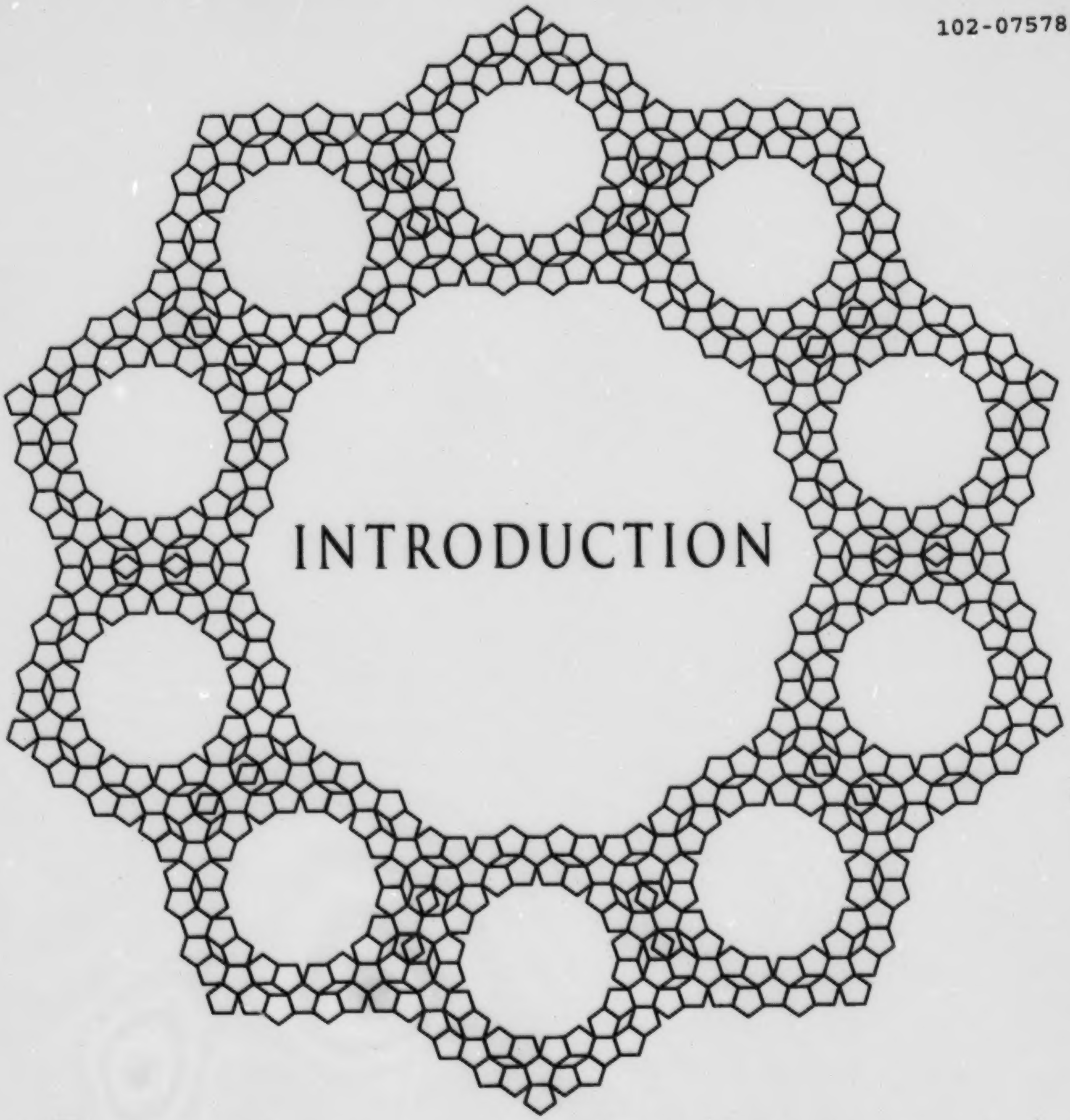


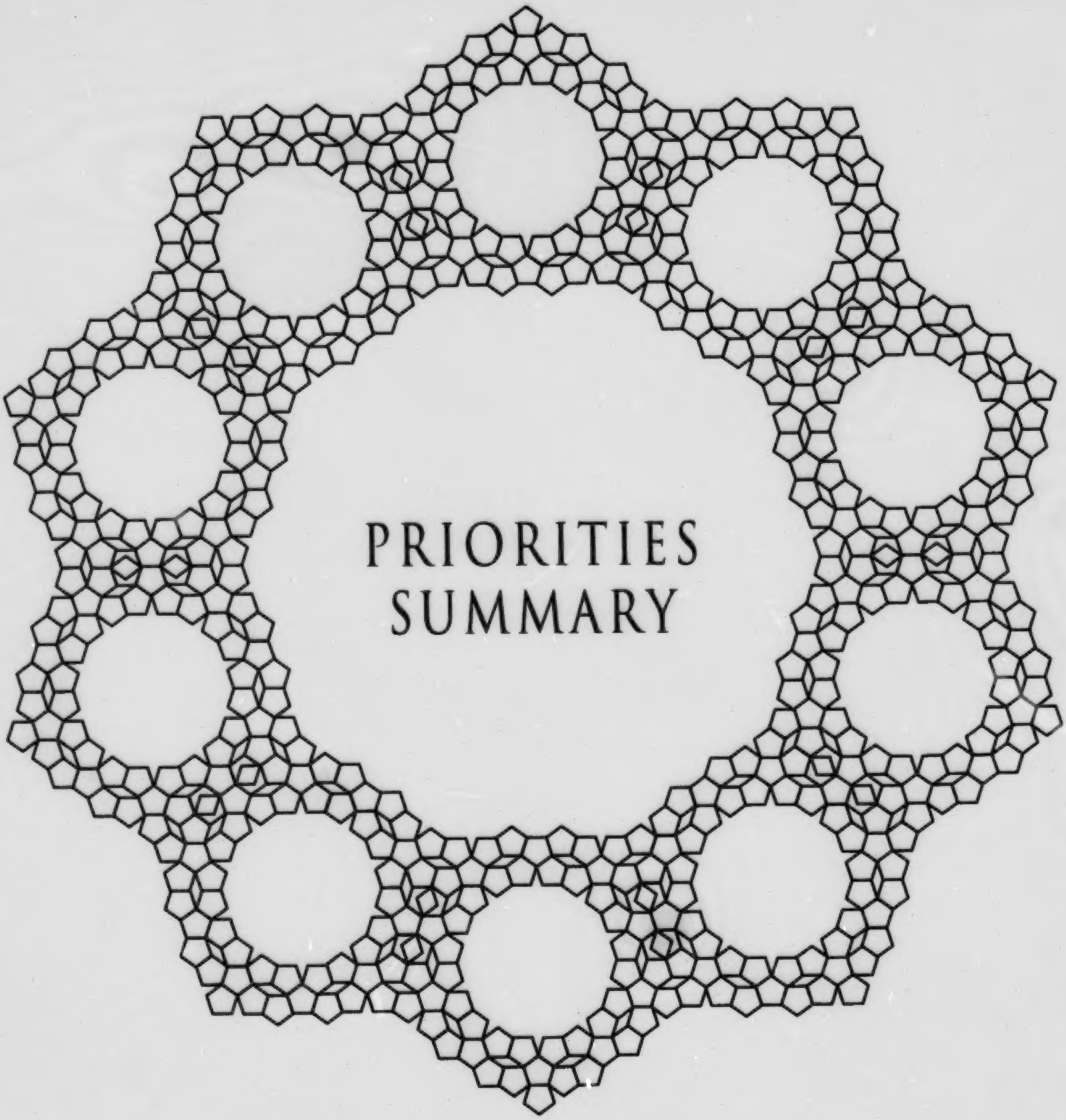
INTRODUCTION

This volume contains material on the priorities the International Joint Commission chose to have addressed during the 1993-1995 biennial cycle. Various groups had the primary or lead responsibility for addressing the several priorities, including the two Boards established under the Great Lakes Water Quality Agreement — the Great Lakes Water Quality Board and the Great Lakes Science Advisory Board — as well as the Council of Great Lakes Research Managers, the Indicators for Evaluation Task Force, the Lake Erie Task Force and International Joint Commission staff who arrange for the review of Remedial Action Plans under Annex 2 of the Agreement.

The priorities summary includes brief overviews and recommendations made by lead and supporting groups on each priority. References to more detailed material in subsequent chapters are provided at the end of each priority summary.

The following chapters are the reports of the various groups. No attempt has been made to harmonize the chapters, as each represents the views of the group which produced it, as it provides its independent advice to the Commission.

OUR FUTURE



PRIORITIES SUMMARY

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SCIENTIFIC CHALLENGES FOR DECISIONMAKING

Toxicological Mechanisms

The highest priority for future work on the endocrine effects of environmental exposures to chemicals is the development of research strategies based on more sophisticated analysis of behavioural and endocrine endpoints that might be expected to be influenced by developmental exposure to hormonally-active agents.

Conclusion and Recommendations

In animals, certain chemicals in the environment can cause a range of effects on the endocrine and endocrine responsive organ systems. An important subsequent question is to determine if these effects are observed in, or can reasonably be extrapolated to humans under environmental exposure conditions.

The Science Advisory Board recommends that:

- **cooperative efforts occur between the governments, academia, the general public and industry to focus research:**

1. to identify which, if any, environmental exposures to chemicals are or have the potential to be endocrine modulators in humans. For those chemicals identified, what are the exposure and dose-response relationships that define the potential for adverse effects?
2. to identify what effects and disease state in humans may be linked to endocrine modulation as a result of exposure to chemicals in the environment, and at what stage of development is the human most susceptible to these effects
3. to identify the mechanisms of action of environmental exposures to chemicals relative to endocrine modulation, and how such knowledge can be factored into the risk assessment process
4. to determine if structure/activity relationships can be developed to accurately predict which environmental exposures to chemicals have the potential to modulate the endocrine system
5. to determine if sensitive biomarkers of endocrine modulation can be developed and validated for use in animals and humans exposed to chemicals in the environment
6. to determine in animals if environmental exposures to chemicals that are endocrine modulators can be differentiated from other environmental stressors, such as loss of habitat, malnutrition, or changes in ecosystem dynamics that can similarly exert effects on the endocrine system
7. to determine in humans if environmental exposures to chemicals that are endocrine modulators, can be differentiated from endocrine effects that are caused by endogenous, dietary or other lifestyle stressor factors (loss of jobs, etc.). How can their interactions be studied?
8. to identify chemically-exposed cohorts that can be used to study the potential for environmental exposure to chemicals to alter endocrine function or endocrine responsive organ function
9. to identify if technologies can be devised to control the release of endocrine modulators. Can more effective technologies be developed?

(Science Advisory Board, Chapter 2, p. 97)

Weight of Evidence: Approaches to Decisionmaking in the Face of Uncertainty

Although everyone recognizes that there is a kind of credibility continuum between the first suggestion that some factor is a hazard to life in the Great Lakes basin and strict scientific "proof" that this suggestion of harm is indeed the fact, finding the point in the continuum that indicates a sufficient level of proof that the factor is more likely than not a true hazard, however, is more difficult. Many such early suspicions turn out to be wrong. Yet, waiting for absolute assurance capable of convincing even the most sceptical scientist, may result in irreparable and irreversible damage to the ecosystem and human health. Premature alarms risk socioeconomic havoc and can discredit public policy as being poorly supported by the scientific fact.

The decisionmaking process is divided into two complementary arms: risk assessment, which results in hazard identification and uncertainty analysis; and risk management, which particularizes the policy to a geographical and temporal application, resulting in a way to proceed for the present with appropriate safeguards against a wrong decision.

- Risk assessment includes a recognition of the contributions of the science of causality and of expert panels. The Science Advisory Board's Workgroup on Ecosystem Health has expanded the scientific questions usually addressed in risk assessment by some deeper considerations of the long-term effects of a potentially hazardous factor in itself, its pathways in the environment or in the host response to it. This important expansion of scientific criteria is contained in Appendix A of the SAB chapter to facilitate its use independently. Good risk assessment is expected to produce a clear exposition of uncertainties in the analysis. It should ultimately result in risk characterization, which then becomes the scientific input into decisionmaking, the best available at that moment in time.

- Risk management accepts the risk characterization and analysis of uncertainty as the scientific input into decisionmaking. It also recognizes the human right of persons most closely affected by decisionmaking to enter into the decisions concerning risk acceptability and risk management. Risk acceptability will frequently relate to civic science and community values, rapidly becoming the hallmark of an informed citizenry. Several principles guide risk management, including the precautionary principle, reverse onus and ethics. Input into risk management includes formal consideration of the legal, socioeconomic, equity, and cumulative environmental and human health impacts on the affected community. Appropriate alternatives available for replacing or reducing the hazard should be considered.

Transparency in the processes of risk assessment and risk management is needed, as well as disclosure of the level of proof required in a particular decision, and safeguards after the decision is made to monitor for any unanticipated results of the policy.

6 The Science Advisory Board recommends that:

- **scientific risk characterization formally include disclosure of: (1) choices embedded in the design of supporting research; (2) modifiers of risk factors used; and (3) all relevant uncertainties.**

- **risk characterizations prepared for environmental decisionmaking explicitly examine the potential indirect consequences resulting from the characteristics of the hazard, pathways and host response as outlined in Appendix I of this section.**

- **decisionmakers seek out or recommend relevant valuation assessments, legal and regulatory analysis, socioeconomic assessments, equity analysis, ethical analysis and cumulative impact assessments as necessary inputs into risk management decisions.**

- **Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties and consequences involved.**

- **the level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated.**

- **the risk of non-action be included in deliberations on risk management.**

- **Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of progress toward the desired goal, or conversely as an indicator of a wrong decision.**

- **Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers.**

- **further development of an ethical basis for ordering and prioritizing goals of human health and/or environmental integrity, when there is a potential conflict between those goals, be undertaken.**

(Science Advisory Board, Chapter 2, p. 80)

Climate Change

A Global Climate Change Workshop was convened on December 6-8, 1993 in Ypsilanti, Michigan by **National Oceanic and Atmospheric Administration's** (NOAA) **Great Lakes Environmental Research Laboratory** (GLERL), the Cooperative Institute for Limnology and Ecosystems Research (CILER) and the Great Lakes Commission. The Administrator of NOAA had charged GLERL with developing the United States component of a binational Great Lakes global climate change study. The objective of the workshop was to link the study with the ongoing initiative coordinated by the Canadian Atmospheric Environment Service. The purpose of the workshop was:

- to assess the current status of global change research and impact assessment in the Great Lakes
- to identify unmet needs in these areas
- to develop a United States Great Lakes Climate Change Research Plan to address these unmet needs and lay the foundation for basinwide adaptive strategies.

The workshop included nine formal presentations and five breakout discussion groups focussing on issues related to: economic/social assessment and impacts; ecosystem and public health; landscape/long-term measurements; physical/climate systems; and water policy and management.

The main conclusions and recommendations can be summarized as follows: potential effects of climate change and variability could have several consequences for the economic, environmental and social fabric of the Great Lakes basin:

- a study should be undertaken to investigate the potential impacts of climate change and adaptive and mitigative strategies to address the potential consequences

- the proceedings of the workshop should be used as a basis for a United States Plan of Study.

A U.S. committee met in the fall of 1994 and spring of 1995 to plan a binational symposium to develop a Binational Implementation Plans as a terms of reference for the Great Lakes - St. Lawrence Climate Change Project.

The goal of the Binational Implementation Plan is to undertake research which will improve the understanding of the complex interaction between climate change and variability, the environment, and our social and economic systems so that informed regional adaptation responses can be developed for the sustainable management of the region.

The research framework is flexible and comprehensive and provides a basis for further research initiatives to add to the knowledge base of the binational project as opportunities arise. Specific study areas that would benefit from additional research include:

- assessment of the human health impacts of climate change
- impact of climate variability and change on Areas of Concern and implementation of remedial efforts
- impact of climate variability and change on groundwater, ecosystem processes, wetlands, biodiversity, lake circulation and water quality
- impact of changing agroclimatic conditions on agricultural practices
- impact of climate change on long-range transport and atmospheric loadings of toxics.

Much of the current climate impact assessment research has focused on the southern portion of the basin, while Lakes Superior and Huron, the St. Lawrence River, and inland waterbodies have received less research.

Conclusions and Recommendations

The Science Advisory Board congratulates the Parties for developing a comprehensive and integrated research program that addresses many of the major issues concerning climate change relevant to the Great Lakes. It is noted that a symposium is planned for 1996, as a followup to the binational meeting initially held in Chicago in 1988. This symposium will provide a major opportunity for researchers to discuss and incorporate current global and regional efforts in order to develop the 1988 proposal to develop an integrated study of the Great Lakes basin as a regional pilot project for an international response to global climate change. This recommendation was recently reiterated by the IJC in their *Seventh Biennial Report.*

The proposed Binational Implementation Plan develops such an integrated study, providing it receives Parties' support through to its completion in 2001. Accordingly, the Science Advisory Board recommends that:

- **the Parties be encouraged to support the completion of the binational implementation plan through to 2001 according to the scheduled timeline as indicated in Table 6.**
- **a quinquennial symposium on climate change in the Great Lakes basin be sponsored by the Parties and be sustained following the event planned for 1996, as an important scientific forum for discussion and to measure progress towards climate change assessment and adaptation.**
- **the recommendation from the 1993 Science Advisory Board report, that the Parties make a long-term commitment to climate change research under Annex 17 of the Great Lakes Water Quality Agreement, and report progress in a holistic and systematic fashion within the context of a State of the Great Lakes Basin Ecosystem report, receive further consideration and emphasis in the Commission recommendations to the Parties.**

(Science Advisory Board, Chapter 2, p. 109)

Followup to Virtual Elimination Task Force

The issue of persistent toxic substances remain a focal point for many Great Lakes constituencies, and similarly, for the **International Joint Commission** (IJC or Commission). Indeed the IJC has proposed a number of policy directions and action steps to address this problem, as demonstrated in its recommendations to the Parties. More specifically, the Commission made special reference to the need for all sectors of society to assist in the transition away from the use, generation and discharge of persistent toxic substances and toward cleaner production processes. In effect, the IJC recognized that an effective virtual elimination strategy must include the issue of **how** to sunset substances in light of the technological, social and economic components that might arise.

The **Science Advisory Board's** (SAB) Workgroup on Parties Implementation recognized the importance of transition mechanisms and planning. The role of these mechanisms and processes in the context of virtual elimination of persistent toxic substances is to facilitate social and other changes, by providing a forum for all those affected to evaluate progress, identify alternatives and agree on priorities.

The Workgroup hosted a Workshop on "Transition to Virtual Elimination" in 1995. The issue for the workshop was **how** to plan for a transition, not **if** phaseout of a targeted substance should occur. The workshop was centred around a case study using polychlorinated dioxins and furans (PCDD/F) as specific virtual elimination candidates.

Taking into account the discussion at the workshop and the deliberations of the Workgroup, and the SAB as a whole, a number of recommendations were formulated. Reference should be made to the text of the SAB chapter for the full set of recommendations. However, the key four recommendations include:

- **The Commission consider planning for the transition to virtual elimination as a priority for further study and research within the next biennial cycle.**
- **The Commission sponsor one or more roundtables to engage the dialogue of stakeholders in the topic, and to further elaborate on how the term should be interpreted and applied.**
- **The Commission actively seek avenues to participate in international dialogue both within North America and beyond to engage in a discussion beyond.**
- **The Commission reiterate recommendation 20 in its Seventh Biennial Report to the Parties, in particular, which state that governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of initiative designed to promote virtual elimination.**

(Science Advisory Board, Chapter 2, p. 105)

Parties' Toxic Reduction Programs

In 1994, the Workgroup on Parties Implementation of the Science Advisory Board sought to investigate the status of toxics reduction programs and related activities by federal and provincial/state governments in the Great Lakes basin. The Workgroup contacted 99 agency representatives across the Great Lakes states, the Province of Ontario, and in both federal governments, and used their responses to create a list of laws, programs and data relevant to toxic chemicals. The following paragraphs summarize the findings of this study:

Laws: All jurisdictions had laws in place to reduce discharges of toxic chemicals. Few of these laws require data collection and few address all environmental compartments. Datasets collected by statutory authority contain compliance information and therefore may be limited to certain types of substances and may vary considerably from place to place in terms of detail, data collection techniques, and timeliness.

Programs: Multi-media toxics reduction programs have been initiated through a number of voluntary industrial agreements. Some voluntary programs exist in local and regional municipalities for the control of household hazardous wastes, and rural nonpoint source reduction activities are sponsored by many agricultural agencies as part of farm environmental planning. Little effort is directed to discharges of toxic chemicals from nonpoint sources, including wellhead (groundwater) protection programs. Many toxics reduction programs have a specific media or contaminant focus and thus are difficult to compare across jurisdictions.

Measurable Results: Very little historical information is available on basinwide ecosystem conditions in the Great Lakes basin. Available data comprises primarily detailed information about localized problems and conditions. As a result of this fragmented database, few agencies have sufficient data to make a comprehensive assessment of ambient water quality with respect to toxic chemicals; few agencies have sufficient data to identify the relative contribution of toxic chemicals made by type of source (for example, agricultural nonpoint sources versus industrial point sources); and few agencies have sufficient data to allow assessment of toxic chemical discharges or receiving water impact trends over time.

It is evident from this review that the Parties have not succeeded in developing joint or binational approaches to toxics reduction programs or data inventories, in part because of differing legal frameworks, different approaches to toxics management issues, and different requirements for data collection and analysis. While the Parties' programs need not be identical, it is the Workgroup's view that the Parties need to improve their ability to compare progress on a basinwide basis if they are to meet their obligations under the Great Lakes Water Quality Agreement.

The Science Advisory Board recommends that:

- **the Commission consider toxics reduction programs as a priority for further action within the next biennial cycle. To further this priority item, the Commission should establish a special task force of the Science Advisory Board, in cooperation with the Water Quality Board and the Council of Great Lakes Research Managers, with a mandate to:**

(a) develop standardized binational mechanisms and criteria to assess toxic chemical management laws, programs and data collection activities

(b) provide advice to the Commission on the design and implementation of such activities in order to assess toxics loadings to the Great Lakes basin.

- **the Commission reiterate and re-emphasize to the Parties the recommendation from the Commission's *Seventh Biennial Report on Great Lakes Water Quality*, which stated:**
    - **Governments adopt a specific, coordinated binational strategy within two years with a common set of objectives and procedure for action to stop the input of persistent toxic substances into the Great Lakes environment, using the framework developed by the Virtual Elimination Task Force.**

(Science Advisory Board, Chapter 2, p. 101)

Pollution Prevention

The Commission's Seventh Biennial Report reiterated a preventive, rather than a reactive or controlling, approach to the elimination of persistent toxic substances from the basin. The Commission asked the Water Quality Board to investigate the application of this approach; the Science Advisory Board joined this effort to address some of the technical, socio-economic and cultural aspects of pollution prevention. The Boards hosted a Pollution Prevention Workshop in Ann Arbor, Michigan on March 29 and 30, 1995; the Water Quality Board Chapter to this report contains a detailed summary of this workshop.

Secure in the strong regulatory underpinning developed over the last 25 years, every agency in the basin is moving toward preventing, as well as controlling, pollution. A few industries adapted this approach in the early 1970s, and it has been formalized in the U.S. Pollution Prevention Act of 1990 and the commitment of the Canadian federal and provincial governments under the Canadian Council of Ministers of the Environment in 1993.

Pollution prevention is focused on the reduction or limitation of the *creation* of pollutants or waste at source, and usually includes interactions on a voluntary basis, consideration of multi-media concerns, provisions of technical assistance by government, and the use of positive incentives, such as award programs.

Several substantial programs were reviewed by the Water Quality Board, including those of the automotive and chemical manufacturers. European practices, particularly in regard to lifetime product stewardship, management of wastes from the household level upwards and consideration of the removal of certain commercial substances from the marketplace, were also discussed at the workshop.

In the longer term, the focus appears to be on a lifecycle analysis of products and application of 'design for the environment' — including disassembly — approach. The full costs of production, from raw material, energy inputs and recycling/reuse or ultimate disposal, must be considered. Wastes must be redefined as useful materials, and material management inventories should supplant waste inventories.

To be most effective, the training and education provided to technical personnel, both in academic institutions and at the worksite, should reflect this broader view; finance and management personnel should also embrace it. Fundamental changes in the production of chemicals are under development and should be encouraged. Barriers, both institutional and regulatory, must be identified and overcome.

The workshop emphasized that: i) regulatory action would continue to be a necessary stimulant to the pollution prevention approach; ii) to be most effective, the approach must extend to all levels of society; iii) energy considerations are one of the basic elements of pollution prevention; iv) a means to quantify specific reductions or eliminations of contamination from pollution prevention should be pursued; v) should it be re-negotiated, pollution prevention should be more thoroughly developed in subsequent Great Lakes Water Quality Agreements.

The Water Quality and Science Advisory Boards jointly recommend that:

> **Significant regulatory barriers prevent extensive adoption of a lifecycle approach to the management of waste residuals and obsolete products as part of a sustainable materials economy. The Commission should encourage the systematic identification of these by the Parties to correspond with the goals and policy of pollution prevention. Lifecycle management should include the concept of reincarnation so that wastes are treated as resources, and managed as such.**

In addition, the Water Quality Board recommends that:

- **Should the Parties determine to re-open the Agreement, consideration be given to augmentation by a more thorough treatment of pollution prevention, including its designation as the preferred approach, extension of the breadth of the application beyond the municipal and industrial sources, and development of suitable guiding principles.**
- **The Parties reflect on their current inventory efforts to determine if reductions due to pollution prevention can be quantified, particularly of persistent toxic substances, and if the introduction of a material management, rather than a waste management, inventory would be timely and appropriate.**

(Water Quality Board, Chapter 1, p. 21)

Lake Erie Ecological Model Prototype

With the beginning of a new biennial cycle in October 1993, the Commissioners assigned a series of priorities and their sub-elements to various **International Joint Commission** (IJC) Boards and Committees. These included, "Ecosystem Framework" and "Wetlands" which were assigned to the Council of Great Lakes Research Managers, and "Pesticide Usage," "Groundwater," and "**Pollution from Land Use Activities** (PLUARG)," which were assigned to the Water Quality Board. These sub-elements are reported on elsewhere in the referenced sections.

The "Ecological Changes" sub-element, initially assigned to the Lake Erie Steering Committee, was subsequently expanded to include preparation of a prototype ecological model of Lake Erie. The committee was upgraded to Task Force status and available resources were redirected in order to achieve this goal.

The Task Force is pleased to report that the modelling approach is showing potential as a sustainable aid in assisting Lake Erie managers to arrive at appropriate policy decisions. In addition, the model is capable of identifying the effects of stressors on the Lake Erie ecosystem, in particular the fishery component. The model structure provides for an understanding, through testing and discovery, of the effects and interactions between stressors, and the linkages between stressors in the lake's ecosystem.

The challenge is to ensure that the modelling exercise, currently in its prototype form, continues beyond this first, rough-cut iteration. To ensure that the model becomes a useable tool must be the Task Force's next step.

The Task Force has laid out a process which, if followed, will ensure that progress continues. With continued collaboration of advisors and the identification of a few additional "leaders," we can better use our limited resources. This approach has been identified by the Council of Great Lakes Research Managers as the hope and challenge for the next five years. The Task Force endorses this approach.

The development of the Lake Erie Ecological Modelling Project has been an extremely positive exercise for the Task Force. We are indebted to the advisors, and especially the LURA Group and Drs. J. Koonce and A. Locci, who participated in making this effort worthwhile.

Recommendations

The Lake Erie Task Force concludes that the model has the potential to be valuable tool for use by Lake Erie managers, scientists and researchers, and has the potential to be adapted for use on other Great Lakes. This modelling exercise reflects the considerable leadership of the Commission in moving towards an understanding of changes to the Lake Erie ecosystem. By starting the development of an ecosystem model, changes can be better understood and even predicted, and thus managers can move forward with a higher degree of confidence.

Through the establishment of a special Task Force on Lake Erie, the IJC has indicated that the Lake Erie priority is of significant importance. By initiating the development of this prototype, the IJC is facilitating progress. We suggest that the IJC continue in this leadership role.

The Task Force recommends that the IJC continue efforts to develop the Lake Erie model through the next biennial cycle.

(Lake Erie Task Force, Chapter 4, p. 157)

Ecosystem Framework

During the past five years, the Council of Great Lakes Research Managers has developed an ecosystem framework. The objective was to develop a schematic diagram to link knowledge about the natural systems in the Great Lakes basin with societal and institutional processes and thereby aid in the selection of research priorities and policy options. The Commission requested the Council of Great Lakes Research Managers to provide advice on applying the methodology to the issue of zebra mussels in Lake Erie as part of its 1993-1995 priorities. The Council held a workshop in Ann Arbor on January 17 and 18, 1995 to carry out this request.

Primarily in response to the introduction of zebra mussels into the Great Lakes, Congress enacted the Nonindigenous Aquatic Nuisance Prevention and Control Act in 1990. The Act establishes an interagency Aquatic Nuisance Species Task Force responsible for developing a framework to reduce the risk of unintentional introductions and to monitor and control nuisance species that are already in aquatic environments throughout the United States.

The Council workshop was designed to help various people representing diverse viewpoints and interests to examine the complex problem of recommending priorities for research on zebra mussels, and to come to decisions that were acceptable to all.

Research priorities for zebra mussels in Lake Erie should be inclusive of preventive and mitigative approaches. Preventive approaches include the identification of potential invaders, their environmental requirements and tolerances, and the determination of preventive measures through the development of legislation and appropriate technology, particularly related to shipping and navigation. After an invasion by an exotic species, mitigative approaches become publicly mandated. Predictive models should then be developed to establish effects on nutrient and contaminant cycling, integrated control strategies through understanding of the consequences of the various control options, and the development of physical rather than chemical control measures.

(Council of Great Lakes Research Managers, Chapter 3, p.145)

Pesticide Usage

Under the Lake Erie focus of the 1993-95 Commission priorities, the Water Quality Board was asked to investigate recent developments in the agricultural sector, with an emphasis on pesticide use and effects. It did so through two sponsored workshops.

The Board verified that, as one of the most actively cultivated areas in the basin (and in North America), the Lake Erie basin continues to receive millions of kilograms of pesticides applied to crops, particularly corn and soybeans. The effects of one pesticide, atrazine, particularly on drinking water quality, appear particularly worthy of further investigation.

The workshops also noted agency support for management practices, including Integrated Pest Management to reduce pesticide use, and the effectiveness of conservation tillage in reducing sedimentation of waterways. Continued support is needed for pesticide inventory development, Environmental Farm Planning on an individual basis, and the application of remote sensing and positioning technology to improve fertilizer and pesticide applications, and to verify progress of conservation tillage.

(Water Quality Board, Chapter 1, p. 48)

Groundwater

Under the Lake Erie priority, the Water Quality Board supported a literature review of groundwater impacts in that basin. The study characterized groundwater flow to the lake, including the transport of nitrate and pesticides via agricultural tile drainage. Deep well disposal activities in the vicinity of the St. Clair River and estimated groundwater flows to portions of the basin were noted; however, the current data base was not judged adequate to derive a total groundwater flow estimate for the basin. The study suggested that a further compilation of groundwater-related research is necessary, as well as field assessments of the potential for groundwater transport through the bottom sediments of the lake. Further determinations of the chemical composition of groundwater discharges was also suggested.

The Water Quality Board recommends that the Commission promote the preventive approach in protection of the groundwater resource and encourage the Parties to proactively implement Annex 16 (the Groundwater Annex) of the Agreement.

(Water Quality Board, Chapter 1, p. 53)

Measuring Ecosystem Health

The original task undertaken by the Subgroup on Measuring Ecosystem Health under the priorities for the 1993-1995 biennium was to prepare a discussion paper on methods for the diagnosis, prognosis, treatment and rehabilitation of ecosystems under stress. It was decided that human health issues in the context of ecosystem health needed to be addressed. The Subgroup contracted with the Chair of Environmental Health, McMaster University (Drs. John Eyles and Donald Cole) for the production of a monograph *Human Health in Ecosystem Health: Issues of Meaning and Measurement* to address this topic. The monograph discusses ecosystem health in relation to human environmental wellbeing in its broadest sense as an essential context for human health. This section addresses human health primarily as defined as an absence of disease, i.e. to highlight for the Science Advisory Board chapter of the priorities report what is known about human disease that flows from exposure to agents within ecosystems, rather than being determined by human genetics, lifestyle behaviours, nutrition or social determinants such as class, poverty, education and self-esteem.

The best evidence for environmental health effects comes from epidemiological studies when such evidence is available. Such studies are limited by the difficulties in assessing the exposures to toxic agents as environmental exposure levels (i.e. accurately classifying who is relatively highly exposed and who is not). Epidemiological studies also require that the outcome — the health effect — be measured accurately. Much of the concern regarding environmental exposures relates to subtle effects: influences on neurobehavioural development, IQ, psychosexual development, and fertility that may be significant if they occur broadly throughout the whole population, although the impact or deficit for an individual is of little consequence. Other outcomes are of high significance for the individual — cancers, birth defects — but are at low risk at environmental levels of exposure. Because these outcomes can be caused by many factors, it is often difficult to determine if an environmental factor is adding to the burden of illness. Environmental health risks can also be estimated by risk assessment protocols using animal data on cancer and birth defect risks. In some situations, health effects that have manifested themselves in occupational settings can reasonably be extrapolated back to environmental exposures.

The environmental burden of illness refers to the proportion of illnesses, of particular health outcomes that can be attributed to particular environmental exposures. If the relative risk of an outcome occurring in individuals exposed in the populations is known and the prevalence of exposure is known, the risk attribution to the exposure in the population, the population attributable risk, can be calculated. Unfortunately, very little precise information exists on exposures to toxic chemicals through the ambient environment in the Great Lakes basin.

Although it is difficult to attribute a specific proportion of the overall burden of illness to the environment or ecosystem degradation, human health is a vital consideration in the ecosystem health paradigm. Ecosystem health internalizes human wellbeing as part of the environment, while a human health focus internalizes environment for individual and community wellbeing. The strength of the metaphor or paradigm is clear. Ecosystem health sees humans as integral parts of nature. The metaphor resonates strongly with core values about ourselves, our identity and our place in the world.

We must recognize in our effects to "measure" ecosystem health and human health as an integral part of it, that "ecosystem," "health" and similar terms are abstracted notions with implications not only for what but also how we measure things. All indicators are goal directed; they essentially monitor "system" change given desired outcomes. All indicators (as they are selected from an unknowable universe of all possible indicators) are normative. "Ecosystem" and/or "environment" is a core value of interest in the identity formation and concerns of populations in the Great Lakes basin. The value sets that determine indicator selection for ecosystem health and human health indicators should be clearly indicated for any developed set of indicators. Separate indicators of ecosystem health and human health are required since their goals and targets are different, in the former case, ecosystem stability, persistence or resilience; in the latter, the disease or illness state of individuals. There is a link, however, between indicators of the health of human populations (public health) and indicators of ecosystem health.

The Science Advisory Board recommends that the Commission, in its priority activities and its advice to the Parties, support further research to determine ambient levels of exposure to toxic chemicals in the Great Lakes basin and incorporate the following general principles for further development of environmental burden-of-illness indicators:

- **continued monitoring of toxins in media, including trihalomethanes, nitrates, microbial contaminants**

in drinking water, PM-10, ozone and sulphates in air, and toxic bioaccumulative chemicals in general

- **systematic synthesis of water sampling results for microbial contaminants that result in beach closings. Consider complementing these with information on symptoms among beach users**

- **inclusion of relevant ambient exposure factors (e.g. time outdoors, based on activity record) and consumption factors (e.g. freshwater fish and wildlife) in population-based health surveys. General population-based measures of body fluid levels of key contaminants (e.g. PCBs or DDE for the organochlorines in serum and breast milk, mercury and lead in whole blood for the metals) could be linked with these and other relevant social factors**

- **surveillance of established environmental health outcomes, such as asthma, such that these conditions may be considered as sentinels for pollution effects**

- **recognition that some human illness indicators are poorly suited to provide useful information on the impact of environmental matters on human health, e.g. most morbidity and mortality data that is routinely collected, including cancer rates**

- **development of longitudinal designs around exposures and conditions of interest to enable stronger inferences concerning relationship between exposure and health outcomes.**

The Science Advisory Board recommends that:

- **the Commission support actions that would lower human exposure to persistent toxic substances such as PCBs and lower concentrations of these substances in human tissues.**

- **the Commission support the development of indicators and scales that measure the environmental component of illness and wellbeing and indices of environmental stress and environmental condition.**

- **the Commission continue to monitor state of the environment and sustainable development reporting in order to inform, in its recommendations to the Parties, regarding Great Lakes basin indicators. As these reports often take a broad-based approach to indicator selection, this monitoring is necessary to help ensure the integration of human exposure considerations into assessments of contamination in relevant fish and wildlife species.**

(Science Advisory Board, Chapter 2, p. 68)

Indicators for Evaluation Task Force

Through the Great Lakes Water Quality Agreement, the Governments of the United States and Canada are committed "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." For more than two decades, numerous programs and measures have been undertaken towards this purpose.

Under Article VII of the Agreement, the International Joint Commission is charged to evaluate Agreement progress and provide advice to governments. To fulfill its mandate, the Commission requires data and information. To assist in reviewing these requirements and to develop a framework within which to conduct its evaluation and develop advice, the Commission established, in 1993, an Indicators for Evaluation Task Force.

The Task Force held an Issues Definition Session (December 2-3, 1993) and an Indicators Workshop (October 5-6, 1994), to acquaint itself with relevant activities and to identify specific indicators to evaluate Agreement progress. It subsequently developed a draft White Paper, which was circulated (May 1995) for review to the Commission's Boards and the Council, workshop participants, and selected others. Based on the comments received, the Task Force prepared a revised, final report containing findings, conclusions, and recommendations. The report has been submitted to the Commission as a separate document, to which the reader is referred.

To obtain a copy of the report, please contact the International Joint Commission, 100 Ouellette Avenue - Eighth Floor, Windsor, Ontario N9A 6T3 or P.O. Box 32869, Detroit, Michigan 48232-2869.

(Indicators for Evaluation Task Force, Chapter 5, p. 173)

Research Inventory

Since the Great Lakes Water Quality Agreement was first signed in 1972, a continuing terms of reference has included examining and advising the Commission on the adequacy of research, and promoting research coordination. Over the intervening years a series of research inventories have been produced to meet these requirements. This responsibility has been a relatively resource-intensive undertaking and during the 1993-1995 biennial cycle the Council completed it through two of its member organizations, the National Oceanic and Atmospheric Administration and the Ontario Ministry of Environment and Energy. Staff at the Great Lakes Regional Office coordinated the requests for information from the principal investigators and forwarded the information to these two agencies.

A series of changes has also occurred in the preparation of the research inventory. For example, information is now collected on research projects undertaken on a much wider variety of topics to reflect the ecosystem approach to management of the Great Lakes Basin Ecosystem. In addition to the research on pollution by nutrients, toxic substances and radionuclides, topics include the introduction of exotic species, land use and wetlands, shoreline and upland habitat, resource management including fisheries, wildlife and forestry, and natural ecological processes. These categories make up a new classification system.

In the past, it has been a challenge to produce and publish the research inventory in a timely manner. The cost has been substantial and the data have frequently been out of date by the time that the document was completed. In addition to undertaking the work through compatible binational systems within the two member agencies, the Council decided to make the inventory accessible through the **Great Lakes Information Network** (GLIN) and through computer disk.

(Council of Great Lakes Research Managers, Chapter 3, p. 140)

Recruitment, Training and Development of Scientists

The current members of the scientific research community in Great Lakes and St. Lawrence River comprise an aging population. The Council of Great Lakes Research Managers has raised the need to replenish this population with well-trained graduates prepared to investigate issues in a multidisciplinary manner.

The Council has concluded that many government research scientists will be retiring by the end of the 1990s; overall production of science and engineering graduates in the basin has risen slightly over the past decade; there does not seem to be a shortage of qualified graduates to replace the present professionals when they retire; and, the timing to recruit qualified graduates to replace the professionals who are retiring in the next ten years may be crucial for the continuity of Great Lakes research.

(Council of Great Lakes Research Managers, Chapter 3, p. 140)

ANNEX 2
(REMEDIAL ACTION PLANS AND LAKEWIDE MANAGEMENT PLANS)

Contaminated sediments have emerged as a major technology and financing challenge for the Areas of Concern (AOCs). Activities undertaken at Collingwood Harbour can serve as a model for the remaining AOCs, which are striving to complete remedial actions. As funding for Remedial Action Plans (RAPs) and Lakewide Management Plans (LaMPs) becomes even more constrained, the importance of socio-economic considerations, particularly in remediating contaminated sediments, is becoming apparent. Priorities must be set so that strategies which incorporate sensible staged completion of costly remedial actions can be developed.

A set of questions to guide reviewers of Stage 1 and Stage 2 LaMPs has been developed. Development of these questions before the International Joint Commission has commenced the review of any LaMPs ensures that all involved individuals understand the Commission's expectations for the content of LaMPs. Questions to guide the review of Stage 3 and Stage 4 LaMPs are under development.

(Annex 2 Review Activities, Chapter 6, p. 177)

Chapter One:

GREAT LAKES WATER QUALITY BOARD

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1.0 GREAT LAKES WATER QUALITY BOARD ACTIVITIES

Introduction

The Water Quality Board, as a participant in the development and execution of the 1993-95 Great Lakes Priorities of the International Joint Commission, had direct involvement in the pollution prevention, pulp and paper, groundwater and pesticides issues described in this chapter. In addition, the Board provided the Canadian Co-Chair for the Lake Erie Task Force as well as a representative to the Indicators for Evaluation Task Force and to the Annex 2 (RAPs/ LaMPs) Steering Committee.

Assigned Board members also provided substantive comment on the Decisionmaking with Limited Information and the Parties Toxic Reduction Program priorities under a Science Advisory Board lead.

What follows is an overview of the four priorities in which the Board had a leadership role: 1) pollution prevention; 2) pulp and paper; 3) pesticides; and 4) groundwater.

1.1 POLLUTION PREVENTION: CURRENT STATUS AND CONTINUING CHALLENGES

1.1.1 Introduction

Virtually every agency in the basin recognizes that a shift in emphasis to pollution prevention has been, and continues to be, appropriate for the achievement of the goal of virtual elimination of persistent toxic substances in the Great Lakes Water Quality Agreement. While there are several definitions of this term, pollution prevention commonly refers to an active application of processes, practices, materials and energy uses that avoid or minimize the creation of pollutants and wastes.

The Water Quality Board and Science Advisory Board of the International Joint Commission, under the 1993-95 Priorities of the Commission, hosted a workshop to review the fundamental issues associated with pollution prevention. Current legislative initiatives, associated programs and projects, emerging considerations and longer-term challenges associated with technology, social and cultural aspects and research and development efforts were all considered. The workshop was held at Ann Arbor, Michigan on March 29 and 30, 1995. This chapter is a report on that workshop augmented by an introductory discussion of the history and evolution of pollution prevention.

Pollution prevention is a mark of the maturation of environmental stewardship. It is frequently viewed as a point of departure from the regulatory control approach of the late 1960s and 1970s, which was most frequently reactive in nature and premised on the deployment of "end-of pipe" control and related removal technology.

One of the first significant corporate pollution prevention initiatives was undertaken by the 3M Corporation in 1975. Operating under the title "Pollution Prevention Pays Program," the initiative had four major thrusts: i) product reformulation; ii) process modification; iii) equipment redesign; and iv) recovery and re-use of waste materials. Within three years, the company estimated that the program had delivered savings of $17 million from their U.S. operations (Thomas Zosel, workshop).

Similarly, in 1973, Union Carbide's Surplus Products Group, which markets process byproducts and wastes, realized $1.2 million in combined income and savings. At approximately the same time, Dow Canada and Diversey Canada transformed waste powder from steel-making into a valuable end product that diverted 4.5 million kilograms (10 million pounds) from landfills to usable applications (Pollution Probe, 1982).

The promulgation of the 1984 Hazardous and Solid Waste Amendments to the U.S. **Resource Conservation and Recovery Act** (RCRA) was a major legislative milestone. These amendments directed the U.S. **Environmental Protection Agency** (EPA) to develop mandatory requirements for the adoption of pollution prevention techniques. In the late 1980s, the U.S. Congressional **Office of Technology Assessment** (OTA) illustrated the need for such an altered approach, noting that "although there are many environmental and economic benefits to waste reduction, over 99 percent of federal and state environmental spending is devoted to controlling pollution after waste is generated. Less than one percent is spent to reduce the generation of waste." The U.S. Pollution Prevention Act of 1990 evolved from this RCRA amendment and the Congressional OTA comment.

The lineage of pollution prevention in Canada is evident in the Federal Environmental Contaminants Act of 1974. The intent of that Act was to move through pollution control to prevention. The enactment of the Arctic Waters Pollution Prevention Act in the same period and a move to outright bans in the use of specific substances or prohibition of particular activities are other aspects of federal government actions that reflect a preventive approach (Verstey 1993).

Developments in Canada culminated in the call for a national commitment to pollution prevention by the Canadian Council of Ministers of the Environment (CCME) in November of 1993. The highlight box on page 22 illustrates typical actions taken by existing facilities in implementing a pollution prevention approach.

Following release of the International Joint Commission's Report of the Virtual Elimination Task Force and the Seventh Biennial Report, under the Commission's Priorities for the 1993-1995 Biennial Cycle, the Commission's Water Quality Board was charged to develop an overview of the application and effectiveness of national, state, provincial and other pollution prevention programs in the reduction and elimination of the discharge of persistent toxic substances in the basin called for in the **Great Lakes Water Quality Agreement** (GLWQA).

In response, the Board supported a selected overview of pollution prevention programs and initiatives by the various governments affecting the release of persistent toxic chemicals into the Great Lakes basin.

During the setting of these priorities, the Workgroup on Emerging Issues of the Science Advisory Board was asked to

Typical actions selected by existing facilities in implementing a pollution prevention approach include:

- improving housekeeping and performing preventive maintenance to minimize inadvertent spills and releases
- altering production processes or parameters; e.g. reducing operating pressures to reduce fugitive emissions of volatile toxic materials
- extended use, reuse, and recycling within a process; e.g. more effective capture and return of metals from rinse tanks to plating tanks in electroplating operations
- reformulation or redesign of products; e.g. reformulated gasoline to reduce volatile organic emissions into the air
- substitute non-toxic or less toxic substances in the process; e.g. the move from solvent based coatings to water-based coatings
- eliminating the use of specific targeted substances

[Final report of the Pollution Prevention Legislative Task Force. Environment Canada, September 1993]

assess the role of technology in achieving the goals of the GLWQA. Subsequently, both Boards cooperated in sponsoring a Pollution Prevention Workshop; deliberations of that workshop make up much of this chapter.

1.1.2 The Legislative Evolution of Pollution Prevention

The U.S. Pollution Prevention Act of 1990

Following the publication of a draft Pollution Prevention policy by the U.S. EPA in 1989, the U.S. Congress declared in 1990 that "pollution should be prevented or reduced at the source whenever feasible." The Pollution Prevention Act has elements that are near universal throughout the U.S. and Canada, namely a call for: i) standard methods of measurement; ii) identification of measurable goals; iii) improved methods of coordinating, streamlining and assuring public access to data collected under federal activities; iv) performance of outreach and facilitation of the adoption of source reduction techniques by the private sector through various support mechanisms, including technical assistance (guidance documents, workshops and other training devices), information clearinghouses, and grant programs; v) identification of incentives and elimination of barriers to source reduction; and vi) establishment of award programs. The language of pollution prevention was subsequently reflected in the reauthorized U.S. Clean Air Act of 1990.

The Pollution Prevention Act, recognizing the existence of a strong regulatory underpinning of effluent control regulations, establishes a four-tiered hierarchy to achieve environmental protection, with the first or most preferred option being source reduction of pollution, followed in descending order of preference by waste recycling, waste treatment and waste disposal as the least desirable option. The federal program under the Act was based on a high level of interaction and cooperation with the states.

Toward the latter part of 1993, the U.S. **General Accounting Office** (GAO) reviewed the implementation of the Pollution Prevention Act. They considered a total of 105 state pollution prevention programs across the U.S. Approximately 20% of the programs were regulatory; 80% were voluntary. The GAO concluded that many state programs did not appear to adequately stress the first option (source reduction) and were inordinately involved in waste recycling, treatment and/or disposal, an approach apparently inconsistent with the policy established by the Act. The GAO also found that, rather than becoming self-sustaining, as called for in the Act, many of these state programs continued to be dependent on EPA funding.

At this initial stage in their deployment, very few of the U.S. pollution prevention programs (federal and state) have established specific reporting and evaluation systems that quantify reductions. Many appear to rely on the **Toxic Release Inventory** (TRI) to provide quantified measures of effectiveness. This U.S. General Accounting Office report, and earlier GAO reports, identified major concerns regarding the use of the TRI, a database not specifically designed for this purpose, to monitor the effectiveness of pollution reduction programs. State managers have encountered several of these difficulties and most have not yet found entirely acceptable alternatives. The question of appropriate quantified measurement will be considered in more detail later.

The GAO report identified specific difficulties with measuring the effectiveness of state programs, singly and on a comparative basis. No common standards of effectiveness exist and most state monitoring systems focus on program efficiency and delivery (ie. number of seminars held, number of plans implemented, etc.) rather than on measuring the reduction of discharges or releases of particular toxic contaminants. Current data on program operations and results were thus unsuitable for aggregation. The data also do not allow determination of the effectiveness of individual programs at the state level. Several causes were identified for these data difficulties: faulty program objectives, often aimed at waste treatment rather than reduction; lack of training in evaluation skills; difficulty in imposing rigorous reporting on voluntary programs; and structural weaknesses in the Toxic Release Inventory database as previously mentioned. A review of information collected on Canadian programs suggests that a majority of these concerns are evident there as well.

Since the completion of the GAO Study, the U.S. federal government has launched the Common Sense Initiative, designed to create and engage multistakeholder teams to focus on the six industrial sectors (automotive, computers and electronics, iron and steel, metal plating and finishing, petroleum refining and printing) that collectively employ four million people, comprise 11% of the Gross National Product, spend more than eight billion dollars on compliance with environmental law and released 180 million kilograms (395 million pounds) of toxic pollutants into the environment in 1992.

In developing strategies for further reduction and elimination of toxic pollution from these sources, the multistakeholder teams, which include local, state and federal government officials along with corporate executives and local and national environmental interest groups, will focus on regulation review, reporting requirements, compliance, permit review, and environmental technology, all in a context of pollution prevention. Pollution prevention will be actively promoted as a standard business practice and a central ethic of environmental protection (Michelle Jordan, workshop).

Canada - Federal and Selected Provincial Initiatives

In keeping with the political structure of Canada, the federal strategic pollution prevention program is being developed in close cooperation with the provinces. In November 1993, the Canadian Council of Ministers of the Environment announced "A National Commitment to Pollution Prevention." In the Ontario region, working closely with the province, the focus has been on forming linkages to the automobile parts manufacturers association, motor vehicle manufacturers association, printing and graphics arts associations, metal finishers and electroplaters. Smaller facilities, such as dry cleaning establishments and individual municipalities, are also actively participating in the program.

A key Province of Ontario initiative is the **Pollution Prevention Pledge Program** (P4). Under this program, initiated in September 1993, facilities *voluntarily* agree to control their emissions to the environment to a level below that required under existing regulations. Facilities are invited to develop their own pollution reduction goals and involve themselves at some level in a four-tiered structure: i) registration and planning; ii) reduction commitment or pledge; iii) reduction achievement; and iv) pollution prevention achievement. The overarching challenge is to reduce the release of some of the persistent toxic and bioaccumulative chemicals by 50% by 1995 and by 90% by the year 2000, based on 1990 levels. A complete description and workbook is available and, by and large, the process is a public one. The first comprehensive report on the P4 initiative should be available toward the latter part of 1995. A few selected programs are described further in the following pages.

1.1.3 Pollution Prevention and the Great Lakes - the Ann Arbor Workshop

As mentioned earlier, the Water Quality Board and the Science Advisory Board convened a workshop on Pollution Prevention at Ann Arbor, Michigan on March 29 and 30, 1995 as part of their exploration of toxic reduction programs and pollution prevention. What follows is a brief synopsis of that workshop.

Pollution Prevention and the Great Lakes Water Quality Agreement

As a region with one of the most developed economic infrastructures in North America, the Great Lakes basin is home to major agricultural, industrial, transportation, energy, consumer, government, recreation and resource extraction sectors. Many of the associated facilities, in resource extraction and processing, and manufacturing in particular, would be considered mature. As a result, while there are significant opportunities to apply fundamental pollution prevention techniques at the process design stage for new or radically altered facilities, other less elemental techniques such as intermediate material substitution and improved containment (including closed cycle operation), are often more amenable to immediate implementation in several sectors.

The Great Lakes Water Quality Agreement of 1978, between the United States and Canada, called upon these nations and associated states and provinces to "institute programs for the abatement, control and *prevention* (emphasis added) of pollution from municipal and industrial sources." Control of pollution from onshore and offshore facilities was also to include "programs and compatible regulations for the *prevention* of discharges of harmful quantities of oil and hazardous polluting substances." With reference to shipping sources, the prevention of pollution from the loading, unloading, or onboard transfer of cargo was also advocated. These references were retained in the Protocol to the Agreement developed by the United States and Canada in 1987.

In its role of assessing the implementation of the Agreement, the International Joint Commission, over the past several years, has emphasized the elimination of discharges of persistent toxic bioaccumulating substances in the basin. In April 1990 it established the Virtual Elimination Task Force to develop a strategy to achieve this goal. In its report, that Task Force (p. 44) expressed the concern that "the vast majority of laws in the Great Lakes still retain the pollution control approach that assumes there is an acceptable level of inputs of all chemicals. The governments' "pollution prevention" approach generally pertains to *control* (rather than prevention), focuses on releases (rather than uses) and attempts to determine *acceptable* levels (rather than elimination requirements)."

In their deliberations, the Task Force noted that "prevention attempts to avoid use or generation in the first place, through process change, product reformulation, and raw material substitution ... The goal is clean production processes, closed loop recycling and elimination of the use and generation of persistent toxic substances." The Commission itself, in its Seventh Biennial Report, endorsed the Virtual Elimination Strategy and its call for prevention of such discharges.

One of the first issues the WQB/SAB Workshop Steering Committee faced was that of defining the term "pollution prevention." Under the Pollution Prevention Act of 1990, the EPA has defined pollution prevention as "the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or waste at the source." Included are practices that reduce the use of hazardous materials, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use. Unlike definitions of "waste reduction," off-site recycling activities nor "any practice which alters the physical, chemical or biological characteristics or the volume of a hazardous substance, pollutant or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or the providing of a service" are not included.

The U.S. federal legislation is focused on ***source reduction***, while many of the state legislative initiatives promote ***toxics use reduction***. While this latter focus is seen by some as a more thorough approach to eliminating the presence of a particular contaminant from the ecosystem, others note that it can be considered a limited approach which is often confined to particular listed toxic chemicals and, frequently, specified manufacturing processes.

Under its Pollution Prevention program, the Ontario Ministry of the Environment and Energy states that pollution prevention is "any action that reduces or eliminates the creation of pollutants." It is achieved through activities that promote, encourage or require changes in the basic operational or behavioural patterns of industrial/commercial/institutional or individual generators. It does not include substitution of one toxic substance for another, treatment, out-of-process recycling or incineration or transfer from one medium to another. It is achieved by raw material substitution, production reformulation, process redesign or modification, in-process recycling or improved maintenance and operation.

A review for Environment Canada examined 23 state laws and isolated no fewer than 10 discreet terms claiming to be synonymous with pollution prevention, including hazardous waste reduction, waste reduction, source reduction, waste minimalization, toxics use reduction, toxic pollution prevention and pollution prevention.

Pollution prevention is seen by many as a broad concept, built on the foundation of waste reduction and waste minimization, augmented through the inclusion of products as well as processes. Dr. Larry Ross of the American Institute of Chemical Engineers Centre for Waste Reduction Technologies has suggested the following 'ideal' definition of pollution prevention as "activities that have the potential to transform industry from material intensive, high throughput processes to systems that use fuel and raw materials highly efficiently, rely on inputs with low environmental costs, generate little or no waste, recycle residuals, and release only benign effluents."

1.1.4 Basin Program Overview

While this report is not meant to provide a detailed account of pollution prevention programs in the basin, a few will be briefly noted to give a sense of the industries involved, the approach taken, and the results achieved.

Initiatives in the automobile manufacturing industry, both by primary producers and by their suppliers, are indicative of industrial activities on both sides of the Great Lakes basin boundary. In the American portion, a voluntary program was initiated in 1991 by the American Automotive Manufacturers Association and the Michigan Office of Waste Reduction Services, managing the project on behalf of the eight Great Lakes States and the federal government.

By early 1994, 16 individual projects under this program had achieved a 20% reduction in persistent toxic releases to the Great Lakes and a 28.9% decrease in the release of toxic substances by the manufacturers to less than a kilogram (2.2 pounds) released for every car manufactured (Automotive Pollution Prevention Project: Progress Report 1994).

Similarly, in Canada, the Motor Vehicle Manufacturer's Association, in conjunction with Environment Canada and the Ontario Ministry of Environment and Energy, has launched several initiatives. One, the elimination of methylene chloride in paint strippers, has resulted in a 37% saving in costs and the elimination of 63,000 liters (17,000 gallons) per year of methylene chloride; this was accomplished with no significant capital investment. Since the initiation of the program, estimated releases of toxic substances have been reduced by 2 million kilograms (Ron Shimizu, workshop).

The focus of efforts in this area has now been broadened to the metal finishing and other auto parts manufacturing facilities. Significant reductions are being achieved in both.

Binational Program: Lake Superior

In response to the Commission's challenge in 1989 to use Lake Superior as a zero discharge demonstration area, the Canadian and the U.S. Federal Governments have linked with Michigan, Minnesota, Wisconsin and Ontario to develop the Lake Superior Binational Program. Pollution prevention is an integral part of the program; specific initiatives include development of a coordinated pollution prevention strategy among the U.S. EPA and three Lake Superior states (Minnesota, Michigan and Wisconsin). The pulp and paper industry has been a particular focus of this effort, with the development and demonstration, supported by the Canadian and Ontario governments, of a pilot chlorine-free bleach kraft pulp process at Red Rock, Ontario.

Numerous linkages have also been forged at the local level, particulary through direct technical assistance to improve operation of wastewater facilities through renewed pretreatment efforts to limit or eliminate toxic inputs to facilities. Similar pretreatment strategies have also involved hazardous waste collection activities and the development of community plans to further prevent and reduce pollution.

The European Experience

Several multi-lateral agencies, including the **Organization for Economic Co-operation and Development** (OECD), the United Nations Environmental Programme and the United Nations Industrial Development Office, have addressed pollution prevention either directly or through green technologies or sustainable development considerations.

The **North Atlantic Treaty Organization** (NATO) has sponsored a study called "Pollution Prevention Strategies for Sustainable Development" involving 14 countries in an information exchange program on pollution prevention policy, education and technology.

A major thrust in Europe is 'clean production,' which is seen as a necessary precedent to clean recycling. This approach is reflected even at individual residences; in Holland it is now compulsory for all households to sort food waste to allow intensive composting. Denmark considers the operation of energy-from-waste facilities, fuelled in part by carefully sorted household refuse as a significant component of its pollution prevention strategy (Hans H. Christensen, workshop).

In 1990, as a result of an extensive lifecycle analysis, the Swedish Government moved to a strategy of banning or phasing out hazardous products. Among the first products reviewed for a retroactive ban was **polyvinyl chloride** or PVC. The government has received a recommendation to phase out PVC by the year 2000, notwithstanding the presence of two million tonnes of accumulated PVC product in Sweden, and an estimated 350,000 tonnes in landfills. Further, given that more than 200,000 tonnes of electrical and electronic products are scrapped annually, a majority of them through incineration, legislation requiring manufacturers and importers to take responsibility for them as of 1998 is now being proposed by the Swedish EPA (Beverley Thorpe, workshop). The target is to have 85% by weight of electronic and electrical waste managed in a more environmentally benign manner by the year 2000 (Business and the Environment 1995).

Generally, several governments are enacting or considering shifting the burden of taxation away from income and profits and towards resource use and generation of pollution. Others are creating incentives for innovative pollution control technologies. For example, the Netherlands allows companies investing in such technologies to deduct the full amount of expenditures from taxable income in the first year, rather than over the usual 10-year depreciation period (Focus: National Center for Manufacturing Sciences 1995).

In Germany, the 1986 Waste Act requires certain manufacturers to reclaim their products once they are no longer useful. Most recently, major manufacturers, such as Xerox, are encouraging leasing of products for ultimate return to the manufacturer so casing and other parts can be used in the production of newer models. Similar product stewardship is being exhibited in the automotive industry, including possible return of spent cars to the manufacturer for disassembly and recycling into new products. Two other thrusts are to reduce the pollutant content of waste, thus enabling further recycling, and to reduce the amount of household waste by reduction in packaging materials.

Workshop Deliberations

Pollution Prevention in the Agreement

Participants at the March 1995 Pollution Prevention Workshop in Ann Arbor were asked to consider a series of questions, one of which was, "Does the current Agreement sufficiently address the policy of pollution prevention and provide ample opportunity for binational cooperation and collaboration?"

Participants felt that pollution prevention was imbedded in the Agreement as noted earlier, and was identified as an important technique towards attainment of virtual elimination by the Commission's Virtual Elimination Task Force. Pollution prevention was seen as one of a suite of programs and options, none of which should support practices inconsistent with pollution prevention. A possible role for the IJC was considered to be to promote some principles to the U.S. and Canadian governments to provide clarity and guidance, including perhaps a set of specific objectives for pollution prevention, in the basin community. An ethic for pollution prevention could be a part of this outcome. These suggestions could find form in Commission Biennial or special reports.

An additional question asked at the workshop was, "Are the governments fulfilling the intent and purpose of the Agreement in the area of pollution prevention?"

Several current voluntary and mandatory approaches were reviewed. Some preliminary observations were:

- regulations are a necessary antecedent to effective voluntary programs
- pollution prevention is more broadly based than government and industry and extends to all levels of society
- programs should be accompanied by clearly defined goals and objectives, developed as appropriate in a global context
- government support and initiation of general pollution prevention education efforts, including those associated with energy use, is strongly advocated as one means of indicating and encouraging the development of clean technology and clean production.

Some concern was expressed specific to the American program that, in a time of budgetary constraints, states may not elect to complete the transfer of program initiatives initially funded by the federal government as originally intended in pollution prevention legislation. It was also suggested by some that the Commission should query the United States and Canada on implementation of the new budgetary and

Generic Characteristics of Pollution Prevention Programs

Widely accepted characteristics of pollution prevention and associated programs include:

- a focus on source reduction and on-site application
- emphasis on multi-media concerns as opposed to earlier single medium approaches
- exclusion or diminuation of waste treatment or pollution control, including off-site recycling and incineration or combustion where energy or product are not recovered
- provision of technical assistance, including on-site technical advice, training and education via means such as information clearinghouses and newsletters
- interaction with generators on a voluntary basis
- establishment of plans and targets, with measurable outcomes and reporting requirements, by participating facilities
- exploration of means of providing data on plan outcomes directly to the public
- use of other outreach options, such as award programs, to encourage further participation

(Canadian Pollution Prevention Legislative Task Force)

deregulatory measures and their impacts on pollution prevention programs.

Prominent among the barriers cited to effective pollution prevention programs were those in U.S. legislation that could respond to certain voluntary pollution prevention initiatives by declaring facilities hazardous waste sites under the Resource Conservation and Recovery Act. The need for the government to continue to focus on its own practices was also emphasized.

It was suggested that an extraordinary effort to reopen the Agreement and alter it to better reflect a pollution prevention approach was not warranted at this time. However, as a renegotiation of the Agreement may well occur in the next few years, any opportunity to enhance its pollution prevention aspects should be taken. In the meantime, the Water Quality and Science Advisory Boards and the Commission could encourage the Parties to further refine the pollution prevention approach and identify a binational role for this approach to protect the Great Lakes through establishment of specific needs and a strategy for their further promotion.

Measurement of Progress

A second group considered the question, "Is a detailed assessment of current pollution prevention activities in the Great Lakes basin feasible and timely and, if so, how should progress be measured?"

As noted previously, consideration of the measurement question often begins with a review of the **Toxics Reduction Inventory** (TRI) initiative of the U.S. EPA. This inventory, developed under Superfund Amendments and Reauthorization Act (Title III, Section 313) of 1986, requires certain manufacturers to report annually to the EPA on routine releases of designated chemicals to the air, soil and water. In turn the agency compiles this information into a Toxic Release Inventory and makes it available to the public in various forms, including a computerized data base.

One of the outgrowths of TRI was the 33/50 Program, established in 1988 under the U.S. EPA Office of Toxic Substances as a voluntary source reduction effort aimed at curtailing the release of 17 specific chemicals. The established target was to lower releases from an aggregate of .64 billion kilograms (1.4 billion pounds) in 1988 to .32 billion kilograms in 1995, a 50% reduction. An interim reduction of 33% was to be achieved by 1992; success would be tracked through annual TRI reports. To date, over 1,300 companies are involved and the EPA has determined that the interim target has been met and are confident that the 50% reduction in 1995 will be achieved.

In the Great Lakes region, EPA estimated that the 33% goal for the end of 1992 was exceeded, with total reductions of 85,500 tonnes (188 million pounds). It also appears that performance will surpass the 50% reduction goal for 1995 (Michelle Jordan, workshop). Not all of these reductions are due to activities within the bounds of pollution prevention; however, they do represent a very significant achievement.

The establishment of the TRI predates the U.S. Pollution Prevention Act of 1990. Recognizing that the inventory was not initially designed to delineate source reduction or pollution prevention initiatives specifically, that latter legislation included a provision that annual TRI reports henceforth "shall include with each such annual filing a toxic chemical source reduction and recycling report." These data are also to be made publicly available.

Concerns have been expressed regarding the use of the TRI to quantify reductions specific to pollution prevention. Beyond the question of the quality of the original estimates, some concerns include the complexity of adjusting for varying production levels, possible underestimation of the long-term contribution of pollution prevention efforts; unavailability of metering devices to measure critical quantities, differences in interpretation among similar reporting facilities, and the ability of a few large facilities to superficially distort regional trends (AWMA Summary 1992).

Indeed, a major concern regarding the TRI is that it accounts for only a small fraction (less than one percent) of the estimated over 10 billion tonnes of industrial pollutants generated in the U.S. annually (David Allen, workshop). Because it was not initially established to track pollution prevention efforts, it remains difficult to separate associated reductions from others that curtail release through increased application of waste treatment and control technology.

Application of a materials tracking system is seen as a far more comprehensive method of tracking the status of particular pollutants (David Allen, Critical Review AWMA 1993). Notwithstanding these limitations, there was consensus that the public focus on pollutant reduction under TRI had a marked salutary effect on the attributed sources.

The Canadian government initiative, the **National Pollutant Release Inventory** (NPRI), shares several of the features of the TRI. It is a voluntary program, formally initiated in the spring of 1994 and currently tracking 178 contaminants from 1,466 facilities. Substances already regulated, such as pesticides or chlorofluorocarbons, are not included in this list. Tracked releases for 1993 total 225,000 tonnes, with sulphuric acid, methanol, ammonia, copper (and compounds), zinc (and compounds), and the organic solvents xylene and toluene being the largest individual releases. These data are available to the public on an electronic database.

The stated intent of the NPRI is to encourage development of pollution prevention plans; as the first data have only become available, the capacity of the system to track progress specific to pollution prevention cannot be immediately determined.

Another federal initiative in Canada is the **Accelerated Reduction/Elimination of Toxics** (ARET) program. It is a voluntary program developed through a multi-stakeholder process focused on persistent bioaccumulative contaminants. The 14 listed A-1 substances are targeted for virtual elimination, with a target of 90% reduction by the year 2000. For the balance of 87 substances, the goal is reduction to levels insufficient to cause harm, with a short-term reduction goal of 50% by the year 2000. The suggested base year to determine progress has been set at 1988.

In the first ARET progress report, the participation of over 200 facilities — private and public — has achieved a reduction of 10,300 tonnes of the selected 101 contaminants since 1988. Emissions of high priority A-1 chemicals has been reduced by 49% from among the user community and total reduction of ARET listed chemicals stands at 37%. Details on the methods for progress reporting are presented for each company; a majority are also reporting under the NPRI.

While they are indicative of progress toward limiting toxic releases into the environment, neither system is dedicated to an exclusive quantification of reductions based solely on a pollution prevention approach.

In considering the question of feasibility and timeliness of a possible detailed assessment of current pollution prevention activities in the Great Lakes, the Commission was encouraged to recommend that governments develop the capability for such a specific measure. It was suggested that perhaps the performance of specific sectors be reviewed to determine the extent to which application of pollution prevention techniques had been successful.

With regard to how progress toward pollution prevention should be measured, the discussion first recognized that no consensus definition of pollution prevention was available. The absence of a single definition resulted in a determination that any inventory must be multi-media and account for non-point inputs, including those associated with air deposition.

Broadening Pollution Prevention Activities

Among the questions posed at the March 1995 Pollution Prevention Workshop were : i) what are the most important cultural socio-economic and human factors influencing pollution prevention efforts and how should they be addressed to sustain progress? and ii) is pollution prevention sufficiently recognized by financial and industrial senior management to lead to a fundamental re-engineering of production equipment and processes?

Pollution control measures traditionally restricted discharges of potentially hazardous substances before they entered the environment. The recognition that "pollutants of concern" exist and present a sustained threat to ecosystem health brought about a shift toward a chemical-specific approach, consisting of both intensified pollution control measures and the reduction in use and generation of these substances.

This focus has progressed significantly from an "end-of-pipe" approach to a holistic view of waste reduction. Essentially, any generation of waste products (i.e. those which cannot be reused, either in that or another process stream) or inefficient use of energy is also a loss of resources. Frequently revenue is a prime motivator in encouraging current pollution prevention practices.

The fundamental and relatively broad question continually applied in the pollution prevention philosophy is, Why is waste being generated? Why are processes not more energy efficient? Why aren't materials utilized that optimize productivity without harm to the biosphere and human health? Searching for answers to these general queries has led industry on a voyage back "up the pipe." By scrutinizing each individual step of the process — from a product's design to its ultimate loss of utility — the responsibility for sound environmental and social practices can be shared by all participants in the transaction from producer and distributor to consumer (Wayne Pferdehirt, workshop).

Organizations such as 3M have moved beyond the traditional, corporate-wide environmental priority-setting exercises in favour of a wide-sweeping agreement that waste must be reduced. In their view, chemical-specific waste reduction priorities are less desirable as they may exclude some members of the workforce; establishing a broad waste reduction goal and encouraging individual participation in each area of expertise fosters a sense of responsibility and accomplishment for everyone. "Rather than have 10 individuals within an 'environmental division' try to develop solutions for processes with which they may be unfamiliar, organizations can now have, in some cases, thousands of people striving for solutions and approaches, perhaps to problems which would otherwise have been overlooked" (Thomas Zosel, workshop).

Design for the Environment

The pollution prevention perspective has most recently come to be applied to the first stages of a product's lifecycle, its design. "Industrial Ecology" has emerged as a cornerstone to this rethinking; it is defined in essence by Graedel and Allenby (1995) as,

> "...the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surroundings, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to components, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital."

By considering industrial systems as somewhat parallel to natural systems, within which any and all available sources of useful material or energy are used by some organism, designers have begun to consider the fate of their products in the industrial, recycling and waste streams (Robert Frosch, workshop). The evolved "Design for the Environment" tools are often referred to as Design for Disassembly, Design for Recycling, Cradle to Grave, Cradle to Cradle, and Cradle to Reincarnation. Each approach strives to minimize generated waste through the incorporation of recyclable materials, removable/replaceable or snap-in/snap-out parts, or take-back items which can be reused in new products.

As a measure of the effectiveness of such modified processes, **Life Cycle Analyses** (LCA) are often employed. The **Society of Environmental Toxicology and Chemistry** (SETAC) defines LCA as,

> "...an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire lifecycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling; and final disposal."

This 'quantifying measure' allows particular areas of energy imbalance to be identified and dealt with, thereby increasing the effectiveness of the entire process. Surprisingly, in many cases, the alternative which appears to be the most environmentally sound frequently requires a very significant energy expenditure for the extraction of materials or the transportation of goods, costs which are extraneous to the manufacturing regime per se but are nonetheless reflected in the final price of the goods and the total use of resources. It is crucial that such energy expenditures are included in any quantification of the impact of any process on the larger ecosystem. Although originally designed for simple products such as disposable diapers and drinking cups, LCA are now considered for more complex goods such as television sets and automobiles as their development continues (Graedel and Allenby, 1995).

Educational Challenges

In the industrial forum, much of the success in organizations such as Motorola and 3M is due to corporate-wide education programs. Because a great diversity of educational backgrounds of the employees must be taken into account, an approach quite different from that of an academic institution is necessary. Rather than lecture-style seminars, "action or exercise oriented" programs are developed to allow for "train-the-trainer" interactions to occur (Eagan et al. 1994). This allows individuals, who are experts in their particular area to participate optimally in discussions and brainstorming activities. Each employee may then offer his/her creative solutions, backed with a sound knowledge of the gains to be made, and a competent understanding of the issue. Effective training and education is a vital underpinning for a successful pollution prevention program in any given organization.

Academic institutions, such as the University of Michigan's **National Pollution Prevention Center** (NPPC), have instigated a "multi-sector perspective" (Jonathan Bulkley, workshop) to pollution prevention. Faculty members incorporate the most current pollution prevention idealogies into their curricula and demonstrate the relationship of pollution prevention to concepts in each discipline including architecture, chemistry, operation management, business law, accounting, chemical engineering, industrial engineering and industrial ecology.

> "Faculty in engineering, business and industrial design need to treat environmental issues as an important element of their design and management courses. Until a greater number of faculty and administrators recognize the value of such innovative topics, teaching in this area will only occur sporadically."
> (Keoleian and Menerey, 1994)

The NPPC has called for a national network of pollution prevention educators to facilitate in the "development and dissemination of pollution prevention education resource compendia" (Jonathan Bulkley, workshop). A national directory of faculty involved in pollution prevention education is available and is a valuable resource for students and staff.

Extending the Circle

Pollution prevention frequently is of financial benefit to corporations and consumers; however, it is typically driven by a suite of established performance values: the drive to be more efficient, more productive, more cost effective, more profitable. These traditional performance values, although often effective measures of the use of scarce resources, "tell us nothing about how any technological development will fit into and be compatible with human life, society and nature" (Vanderburg and Khan, 1994).

The societal context of chosen actions is frequently de-emphasized, although it could be a source of the very values which determine the nature of the ecosystem left for future generations. If the improvements created by pollution prevention are to be sustained and enhanced, human, societal and ecosystemic values must be given higher, if not equal, priority to these traditional performance measures in technology development. Full consideration of healthy workplace design, sustainable healthy cities, worker health and wellbeing, and quality of life is a necessity in modern manufacturing (Willem Vanderburg, workshop).

The incorporation of social factors as an additional measure of progress, particularly in Life Cycle Analyses Impact Assessment, can achieve a balance among financial, environmental and societal costs. Vanderburg (1995) explores the complex interconnection between technological advances and societal/human impacts with the query,

> "Will the plant (or facility) produce higher levels of nervous fatigue? If so, how will this affect the employees, the social relations they enter into at work, in their families and communities and thus the entire social fabric of a society? How will the...designs affect the integrity and viability of the ecosystem in which they will function?"

Ultimately a process which is both financially and environmentally beneficial, yet degrades societal or human values, may be discarded based on this larger deleterious impact.

Many organizations recognize that total review and examination of the selection of materials, product design, marketing strategies, and the product's ultimate fate, is an evolving philosophy at the base of future corporate policy.

A rerouting towards more societal-based impact assessment may be aided by modified educational programs that more accurately reflect the impacts on society. Vanderburg and Khan (1994) examined the formal engineering curriculum of a leading North American university to identify "the extent to which students learn to incorporate an understanding of how technology affects human life, society and the biosphere into engineering theory and design in order to ensure a greater compatibility between technology and its contexts." The categories examined included lectures, texts, tutorials/labs, and faculty publications. On a scale of 0 (No reference to context issues) to 4 (Substantial reference to context with an evaluation of consequences), overall curriculum scored only 0.8, and research publications only 0.3. This result indicates that "most of the courses are contextless" (Vanderburg and Khan, 1994), and that the engineering community "continue(s) to produce new generations of engineers who will approach the negative implications of technology for human life, society and the natural ecology in an "after-the-fact" or "end-of-pipe" manner" (Willem Vanderburg 1995).

Courses, and ultimately the manufacturing process, need to incorporate preventative strategies to reduce or entirely avoid negative implications in the societal or human context (Vanderburg, workshop). Negative feedback can be used to recognize and isolate design weaknesses, thereby allowing for appropriate corrections before they can detrimentally impact the outcome. Building negative feedback into corporate-wide strategic planning and product and service development could create "win-win" situations for all parties involved, from the corporation who will break the mitigation cycle, thereby reducing costs and wasted energy, to the consumer who can invest in sound products that don't detrimentally affect the health of their families or the ecosystem (Willem Vanderburg 1995).

By identifying the limitations of current tools and approaches, the assumption that they are the complete solution to our pollution concerns is effectively diminished. Innovative technologies avoid "end-of-pipe" solutions, and instead seek and continually adjust for an balance in which appropriate societal values are reflected in the manufacturing process.

Technology As An Enabler

Introduction

Technology is broadly defined as the means and process by which society produces the substance of its existence. It comprises five basic elements: tools/machines, energy, materials, skills and organization of work. The particular combination of these elements determines the technological path of society, and ultimately the efficiency of the operation and the waste generated. According to Nathan Rosenberg (workshop, 1995), the development of technology is fundamentally a market decision, driven by forces endogenous to the larger economy. Because of the relative abundance of space and natural resources, an inherently resource-intensive industry has been established in North America that substituted natural resources, wherever possible, for relatively scarce labour and capital.

The economy of the Great Lakes region exemplifies this, as it is founded on strong natural resource advantages: water, coal, iron ore, timber and mineral deposits. The sheer scale of human enterprise required to convert virgin resources into materials for processing, manufacture and ultimately wastes, both residuals and obsolete products, has created a problem and a challenge similar to the paradox of technology itself: the industrial economy, provides societal products and benefits, but also causes environmental damage and offers the technical means to repair that damage (Federal Reserve Bank of Chicago and The Great Lakes Commission, October 1985; National Academy Press 1989).

In order to manage technological change to address environmental problems, the role of research and development in encouraging innovation, development and diffusion of technologies must be understood. Rather than a linear process arising from the methodical application of basic research, the economic view of technology suggests that market forces are most pertinent to the role of technology. Their role is primarily one of finding new ways of delivering products to markets at lower cost.

> "The process by which new technologies come into the world is much different from the path suggested by the linear model; one way of seeing this is to look into the composition of **research and development** (R&D) activity. With U.S. Research and Development, what becomes immediately apparent is that it is mostly development. In fact, for several decades now, development alone has constituted two-thirds of R&D. One-twelfth of all R&D is spent on basic research — research motivated purely by scientists asking fundamental questions about the nature of the universe — without any concern for practical applications. The rest, about a quarter of R&D, consists of applied research.
>
> The great bulk of R&D is spent on improving old products. If you ask vice presidents in charge of research in big American firms what they are spending their research money on, improving old products or inventing new ones, they reply that about 80% of R&D goes to improving or modifying old products, and only 20% to developing new ones."
>
> *Nathan Rosenberg*

Thus, it is largely immediate and short-term market opportunity that is the significant driver of R&D carried on at approximately 12,000 scientific research laboratories operated by private industry. Given this capability, and the nature of the R&D enterprise, it is clear that the initial success of early pollution prevention efforts, often characterized as the harvest of low-hanging fruit, needs to be augmented by economic policies that encourage market behaviour based on full environmental costs, and incentives to promote research on the dual goals of green design: waste prevention, and improved materials management (U.S. Congress, Office of Technology Assessment October 1992).

Waste Prevention: Green Chemistry

The role of scientific research in the chemical industry in the United States is more closely allied with innovation, development and production than in any other industrial sector. It also comprises a larger share of basic research as a percentage of total R&D effort, and is ranked at the top in terms of total R&D financed by private funds (Rosenberg 1994). As external costs of potential environmental liabilities and pollution control increase, the attractiveness of benign organic synthesis, i.e. a method of avoiding the formation of hazardous substances, yields a focus beyond the creation of the target molecule. Management of reaction byproducts, many of which formerly ended as wastes to be managed, reused, recycled or ultimately released to the environment, is now a crucial consideration.

Dr. Russell Farris, of the Office of Prevention, Pesticides and Toxic Substances, U.S. EPA, presented an overview of the emerging field of green chemistry to the pollution prevention workshop. The summary which follows is based extensively on his transcript.

One of the primary criteria for evaluating a synthetic pathway in the manufacture of a chemical product is the yield of the process. Yield has been traditionally taken as a good indicator of thermodynamic favorability of a particular process under given reactions or manufacturing conditions. From an economic point of view, the yield is, of course, important as an indicator of the efficient use of the feedstocks. Historically, process path selection hinges on the selection of a feedstock. There is no doubt that the selection of feedstocks, based on cost and availability, and the use of yield in evaluating a synthetic scheme, will continue to be crucial considerations in chemical manufacture.

However, in view of the increasing costs of waste disposal, treatment and regulatory compliance and the current emphasis on pollution prevention, both by regulatory agencies and the chemical industry, evaluation of a particular synthetic method based solely on maximum yield is no longer valid. Rather, new methodologies may be designed that value an environmentally benign process.

This area of research meets both the chemical industry and society's needs to implement the concept of pollution prevention, and the academic community's need to focus on basic research. The next generation of synthetic chemists will certainly focus on how to build new chemical structures, but they will also be encouraged to incorporate all of the impacts — scientific, economic, social and environmental — into their process selection.

Under a pollution prevention umbrella, design of a chemical product begins with decisions about:

- What hazardous wastes will be generated?
- What toxic substances will be involved in the process?
- What toxic contaminants might be in the product?
- What liability concerns are there from the manufacture, use and disposal of this product?
- What waste treatment costs will be incurred?

By incorporating consideration of all of the scientific, environmental and economic impacts of a particular process from the outset, the proper pathway resulting in effective pollution prevention can be selected.

For many years, the environment movement and specifically the regulatory agencies have concentrated on ensuring that chemical products do not pose unacceptable risk. The focus has since been extended beyond the final product, to all of the substances associated with the manufacturing process. A few of the materials to be considered are:

- feedstocks
- byproducts and impurities
- reagents
- catalysts
- reaction media
- separation solvents
- distillation products

Approaches to Green Chemistry

The vast majority of commercial chemicals produced in the United States today is derived from petroleum feedstocks. While some petroleum feedstocks are environmentally benign, many others, such as benzene, a known carcinogen, are acknowledged as quite hazardous. This has spurred research on alternative feedstocks to petroleum, such as other, more easily renewed biological starting materials. In addition to their short-term renewal cycle, this type of biological feedstock, unlike petroleum feedstocks, is often highly oxidized and highly functionalized, which allows for cleaner transformations and often eliminates the use of heavy metal catalysts.

The chemical industry has begun a review of the feedstocks and processes historically used in the manufacture of some of their most basic products. Monsanto, in the production of aromatic amines, is developing a method of direct amination of nitrobenzene rather than continue the use of hazardous chlorinated aromatics. They are also pursuing urethane and isocyanate production using carbon dioxide rather than the acutely toxic phosgene.

Dupont is using manufacturing methods which incorporate in-situ generation techniques, to reduce the risk of exposure to hazardous substances. These techniques have been applied to processes that use especially toxic substances, such as methylisocyanate, in agrochemical processes.

Alternative Catalysts

Some widely used materials in the chemical industry are also commonly recognized to pose significant hazards. Fluorinating agents such as hydrofluoric acid are well known for both their efficacy and their hazards. Air Products, Inc. have developed a fluorinating reagent that requires no special handling and performs selective fluorinations on a wide variety of substances.

Catalysis promises to make an increasing number of chemical manufacturing processes not only more efficient, but also more environmentally benign. Investigations into new applications of nontraditional catalysts to reduce the environmental impacts of certain reaction types, include the use of light energy as a catalyst.

Computer Design of Synthetic Methodologies

Over the past 25 years, the application of computer software to design synthetic transformations of entire pathways has been attempted repeatedly. Some of these computer programs use extensive databases, some work through logic programs and some through the use of artificial intelligence. The U.S. EPA is promoting the incorporation of environmental considerations into the current major software design programs, as well as the development of new software.

Solvent Alternatives

The environmental consequence of organic solvent use in the manufacture of chemical products has been an issue of concern for many years. The new U.S. **Clean Air Act Amendments** (CAAA) list many **volatile organic compounds** (VOCs), commonly used as solvents, as hazardous air pollutants. A number of ongoing research projects have a goal of reducing the amount of VOCs released by the chemical industry.

One alternative is the use of **super-critical fluids** (SCFs) as a reaction medium. While the usefulness of SCFs as an extraction solvent, a cleaning solvent or in analytical methodologies has been well established, the use of super-critical carbon dioxide (as well as other SCFs), as a reaction medium is now emerging. Recent documented successes include the use of SCFs as a medium for polymerization reactions, free-radical transformations, and in certain catalytic transformations.

Another approach is the increased use of aqueous reaction systems, rather than the established procedure of using organic solvents for synthetic transformations.

With the goal of VOC solvent reduction widely embraced, an obvious alternative is the greater use of solventless and solid-state chemistry. Such reactions do not generate any waste solvent, thus availing disposal or recycling. Solid-state chemistry has the additional advantage of operating under very low vapour pressure, which minimizes the exposure of workers to any inhalation hazard.

Curriculum Development

The incorporation of environmentally benign synthetic techniques into the chemical industry will be accelerated well into the foreseeable future. For these reasons, the U.S. EPA has promoted the development and use of educational materials to formally train students of chemistry and associated sciences at various levels of their education to more fully consider environmental impacts. The materials include:

- Textbook supplements, which parallel the classical chemistry texts but offer environmentally benign alternatives to standard techniques.

- A reference module for faculty, to translate the most recent environmentally benign research into their classroom presentations.

- Laboratory modules that illustrate the experimental principles of benign chemical synthesis through undergraduate experiments.

- Professional training for industrial chemists to demonstrate why pollution prevention is desirable and how environmentally benign chemistry can achieve it.

- The **National Center for Clean Industrial and Treatment Technologies** (CenCITT) has involved industry, government and academia in devising clean enabling technologies and design tools. There are three main elements to this effort: i) Chemical Reaction Pathways, Efficient Materials Utilization and the **Clean Process Advisory System** (CPAS). The first seeks to limit or eliminate creation of byproducts; the second to reduce or eliminate waste and reuse secondary materials, including design for disassembly; the goal of the third, CPAS, is a national computer-based framework that provides information on new environmental and pollution prevention technologies, methodologies, costs, safety and compliance (Focus, National Center for Manufacturing Sciences April 1995).

Synthetic or "green" chemistry has an important and fundamental role in the environmental movement. Through development of appropriate training, knowledge and expertise, chemical synthesis processes can be selected or altered to ensure that environmental impacts are minimized. While there are numerous situations where other pollution prevention solutions or even pollution control measures are appropriate, green chemistry should be the option of first choice, and built into the earliest stages of planning when synthesizing a chemical product.

Materials Management

Much of the solid waste produced in the United States is not directly generated by individual consumers. Municipal solid waste, the focus of much public concern, represents less than two percent of all solid waste regulated under the U.S. Resource Conservation and Recovery Act. In contrast, industrial activities from all sectors produce about 700 million tons of hazardous waste and about 12 billion tons of nonhazardous wastes per year (U.S. Congress, Office of Technology Assessment October 1992; David Allen, workshop). Total waste generation in the United States represents a vast throughput of material, with relatively little recovery (David Allen, workshop). Rather, most goes to land-based disposal, or various forms of incineration.

In assessing the value of wastes as raw materials, it is important to consider both the flows and quality of materials as analogous to the recovery and refinement of virgin resources. It has been estimated that, with the exception of mercury and lead, large quantities of other materials are not being recycled. In some cases, this includes relatively concentrated waste streams that should be competitive with virgin materials (David Allen, workshop).

> "The problem is not waste management, the problem is materials management; where materials go and how they are used. It is a peculiarity, at the least of the U.S. system, that on the virgin materials side, all sorts of heavy metals and toxic substances move relatively easily with regulations that keep them fairly safe, but the instant they become wastes, the regulations become contorted and complicated. There is something odd about the two sides of the system. They behave very differently, and yet they ought to be connected in the sense that technologically the output side should become part of the input side, but we have a kind of schizophrenic approach to dealing with it."
>
> *Dr. Robert Frosch, John Fitzgerald Kennedy School of Government, Harvard University*

In reviewing the barriers to the efficient use of materials (virgin or recycled), Dr. Frosch introduced participants at the Pollution Prevention Workshop to the aid, LOITER:

Liability	**O**rganization	**I**nformation
Technology	**E**conomics	**R**egulation

The barriers associated with each of these elements are not necessarily in any particular order or rank; they tend to be nested within each other. If a particular industrial use of materials, or the reuse of the material, is technologically possible, it may not be economically feasible. If it is technologically and economically feasible, the information necessary to support acceptance and practice may not be widely available. When these matters are resolved, there still may be internal and external organizational barriers. Even in large well-integrated companies, technology often does not easily cross barriers, even when the information is available, due to other management or organizational difficulties. Incentives may not be sufficient for diffusion of technology even if it is economical and even if the information is readily available to encourage adoption (Robert Frosch, workshop).

To attain material and energy efficiency and avoid a one-way flow of materials, a broad view of the industrial system, evolving towards a closed system, is necessary. Such a system is viewed not just in terms of controlling and managing wastes by one user, but rather in terms of sequential uses of materials by other industrial sectors. This view of wastes as "material" should include both residual wastes and obsolete products.

Such an approach suggests broadening the design of product and process to include the intentional design of the byproducts and the waste materials. Reuse of the latter does not necessarily occur in the same facility or in the same industry as well; rather, such materials could be available to anyone in the marketplace. The issue becomes not whether a waste coincidentally can be used in some later process, or otherwise be beneficial, but rather whether it is a resource deliberately made available for use by the whole economic industrial system, thereby contributing to improved efficiency and sustainability.

> "This is obviously a very complicated question and one that is unlikely to be dealt with by actually designing the system and attempting to implement it. It is more likely to evolve by putting incentives into place that encourage industries to work with each other to develop such an "industrial ecosystem." The feedback value of incentives is important so that the use of materials is considered not only in squeezing the most economic value out of material inputs through the design of the product, but also in terms of someone's eventual reuse. Of course, regulatory mechanisms could also play a role. I regard "takeback" legislation as simply being an attempt to put a feedback loop into the industrial system. It is not necessarily the case that the producer of the material will be the best one to reuse it. While this may frequently be the case, in some instances, it will be elsewhere in the system where the best reuse will be found."
>
> *Dr. Robert Frosch, John Fitzgerald Kennedy School of Government, Harvard University*

An Ecosystem Approach

In pollution prevention, a range of scales or limits encompasses lifecycle design to green chemistry. These can be delineated as follows: (David Allen, workshop)

- Macroscale: Lifecycle design/assessments, modelling and large-scale ecosystems. Flows of materials in regions and countries, and relationship with the biosphere.
- Mesoscale: Redesigning processes, facilities and their operation.
- Microscale: Molecular development through green chemistry and benign molecular pathways.

These three elements comprise a third generation of pollution prevention, following housekeeping initiatives and the separation technologies/material substitution) (David Allen, workshop). At the macroscale, the critical tools are those related to pollution prevention measurement (an issue dealt with elsewhere in the workshop) and those allowing the assessment of material flows in products and sectors, so that critical waste streams can be targeted for pollution prevention. At the mesoscale, the development of quantitative flow-sheet analysis methodology to permit the systematic analysis of processes could enable a residual material from one process stream to be transferred to another process stream as input. One such approach, called Mass Exchange Network Synthesis, has relevance as an alternative to zero discharge as a goal for pollution prevention, where zero is not feasible (David Allen, workshop).

At the microscale, specific developments such as the use of water-based coatings, biocatalysis in chemical manufacture, and product design incorporating such standards as the new ISO14000, are all applicable.

Findings and Recommendations

The substantial progress made thus far under pollution prevention has occurred primarily from selective use of proven technology and improved management. The most significant challenge and opportunity, however, lies in the innovation, adoption and diffusion of new technologies and applications in the areas of waste prevention and materials management. Ultimately, the latter element includes consideration of product lifecycles, and is key to the creation of a sustainable materials economy. Such an approach requires the collaboration of government and industry in a Great Lakes regional materials management system, to support the development of secondary markets as an incentive towards efficient resource utilization. Such a management system is not envisaged in terms of a central planning authority, but rather as an important part of the market system to be implemented by industry.

1.1.5 Workshop Findings

General

- In the last half decade, the number of programs described as pollution prevention in effect in the basin has increased substantially. While initial regulatory efforts and frameworks were and are crucial, there is a strong emphasis on voluntary programs. Many industrial sectors and its associations are working with federal, state and provincial and local government agencies to tailor plans to the specifics of each sector and facility.
- Pollution prevention, in displacing the "end of pipe" or control approach, is successfully penetrating through the process management level to more senior executives in both the corporate and regulatory sectors. However, many of the myriad activities and practices in the basin are still not captured under voluntary or regulatory pollution prevention programs.

Quantification

- No common baselines or methods have been developed for a cumulative quantification of toxic reductions specifically due to pollution prevention programs and projects. Thus, in most cases, it is difficult to sum the achievements of the various preventative initiatives toward reductions in toxic discharges to the basin, both generally and toward the virtual elimination of persistent toxic substances goal in the Agreement.
- The traditional suite of performance measures (many of which are based on economic parameters) applied in the manufacturing and service sectors is not broad enough to accurately encompass societal, human and ecosystemic impacts of decisions. Measures of progress

must be enhanced to include societal considerations as well as measures based on science and technology and traditional economics.

- There was significant support for a materials inventory, rather than a waste inventory, database management approach.

Modification of the Great Lakes Water Quality Agreement

- An immediate revision to the Agreement to elaborate on a pollution prevention approach was not deemed necessary. There was support, however, for the Commission involvement to encourage the development of guiding principles or ethics, as well as objectives for the extension of the pollution prevention approach.

Extension of the Concept

- Many pollution prevention activities have focused largely on industrial applications; further extension of a pollution prevention approach to numerous other sectors, including agriculture, transportation, merchandising, government and the individual household, would be appropriate. Use of a preventive approach on this broad scale will be necessary if desired progress is to be achieved.

- The pollution prevention approach, in its embrace of the Design for the Environment and Life Cycle Analysis, and through application of concepts such as lifetime product stewardship and further inclusion of the user or consumer, now extends beyond the boundaries of any given facility into the realm of broadly based social practice.

- A preliminary review suggests that the formal education process is not adequately attuned to providing students with a balanced understanding of the intricate relationship between science, technology and the societal context, particularly as applied to pollution prevention and ecosystem quality.

Technology

- Proven technologies with potential for more extensive application to pollution prevention include: design for the environment; renewable energy usage; and energy conservation information management.

- The greatest needs for technological innovation were identified as: separation technologies; improved process design; and further implementation of disassembly design.

- The most immediate and apparent benefit to be gained from pollution prevention efforts would be extending of the successes of major facilities and corporations to small business through:
    - "one-stop shopping" for regulatory and technical assistance
    - partnerships with larger, client industries to secure technical expertise on waste-management issues
    - a more extensive recycling infrastructure to accommodate smaller quantities of byproduct materials.

- Further incentives need to be identified and implemented to encourage the innovation, adoption and diffusion of technology that prevents waste generation through continuous process improvement, encourages efficient energy use, establishes a regional materials management system, and promotes the research and development of green chemistry.

- Full economic impacts need to be identified in any strategic planning process to ensure an orderly transition toward sustainable practices. The costs associated with development of feeder materials as well as the management of byproducts and the ultimate fate of the product must be considered.

1.1.6 Water Quality Board Recommendations

The Water Quality Board recommends that:

- **Should the Parties determine to re-open the Agreement, consideration be given to augmentation by a more thorough treatment of pollution prevention, including its designation as the preferred approach, extension of the breadth of the application beyond the municipal and industrial sources, and development of suitable guiding principles.**

- **The Parties reflect on their current inventory efforts to determine if reductions due to pollution prevention can be quantified, particularly of persistent toxic substances, and if the introduction of a material management, rather than a waste management, inventory would be timely and appropriate.**

1.1.7 Recommendation of the Science Advisory Board and the Water Quality Board

- **Significant regulatory barriers prevent extensive adoption of a lifecycle approach to the management of waste residuals and obsolete products as part of a sustainable materials economy. The Commission should encourage the systematic identification of these by the Parties to correspond with the goals and policy of pollution prevention. Lifecycle management should include the concept of reincarnation so that wastes are treated as resources, and managed as such.**

1.2 REVIEW OF DEVELOPMENTS IN THE PULP AND PAPER INDUSTRY

1.2.1 Introduction

Seventy-two pulp and paper mills currently discharge effluent directly into receiving waters in the basin, 18 in Ontario, and 20, 20, 12 and 2 in Michigan, Wisconsin, New York, and Ohio respectively. Effluent limitations have been based on factors such as production process characteristics, product, quantity produced, the age and location of the mill, and the capacity of the receiving waters. Locations of these mills are given in Figure 1; the numbers correspond to those assigned to facilities in Table 2.

Traditionally the pulp and paper industry has played an important role in the development of northern communities in the Great Lakes basin, particularly in Canada's resource driven economy. In many, the pulp and paper industry is the principal employer and main source of tax revenue. This is especially true in northwestern Ontario, along the north shore of Lake Superior (Bonsor et al. 1988).

Discharges from pulp and paper mills contain conventional pollutants and chlorinated organic substances. Historically pollution abatement strategies have been directed at the conventional pollutants, which include **total suspended solids** (TSS) and **biochemical oxygen demand** (BOD). Pulp production results in considerable quantities of suspended solids and high BOD waste streams, which deplete dissolved oxygen in receiving waters and harm benthic organisms and fish if inadequately treated. Secondary treatment at many sites has led to a significant reduction in these conventional pollutants.

During the mid to late 1980s, studies by the U.S. EPA and the Ontario Ministry of Environment showed that bleached kraft pulp and paper effluent contained quantities of persistent toxic substances, including **2,3,7,8-tetrachlorodibenzo-p-dioxin** (TCDD) (the most lethal member of the dioxin family), and **2,3,7,8-tetrachlorodibenzofuran** (TCDF) (furan), in the subpart per billion concentration range, and numerous other undifferentiated chlorinated organics. These studies also noted the regulatory mechanisms by which other jurisdictions and nations planned to measure and control the release of these contaminants, in particular the use of **Adsorbable Organic Halogens** (AOX) in Ontario, or **total chlorinated organics** (TOCL) control in most European countries, and dioxin limits in the United States (WQB 1989).

The historical and current impact of pulp and paper effluent is evident in 15 of the 43 **Areas of Concern** (AOC) identified by the Water Quality Board as areas of significant degradation and ecosystem impairment in the Great Lakes basin.

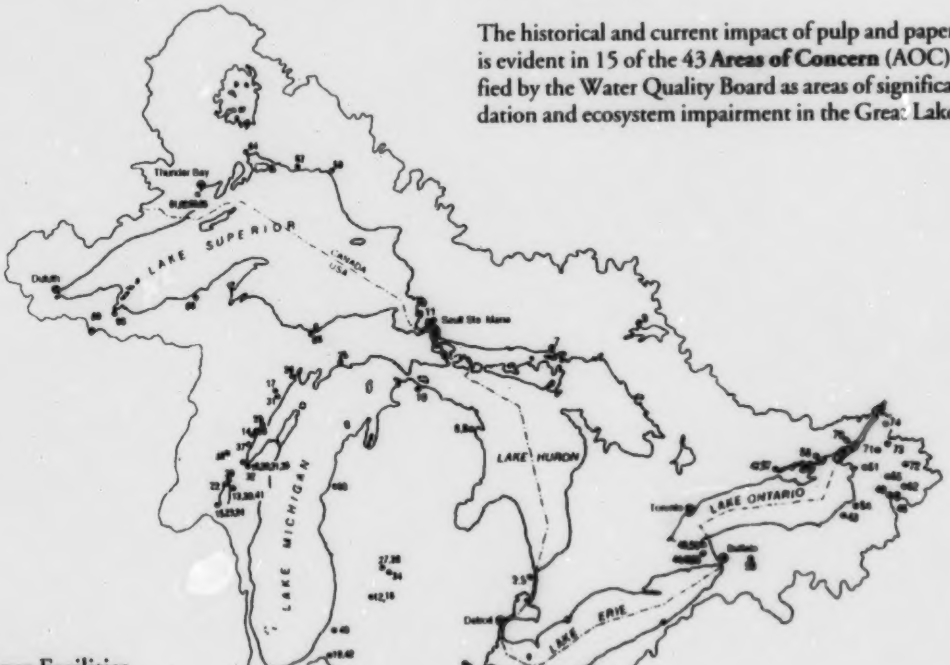


Figure 1.
Pulp and Paper Facilities
in the Great Lakes Basin
(See Table 2, p. 46 for Facility Names)

1.2.2 The International Joint Commission's Interest in the Pulp and Paper Industry

In its 1990 *Fifth Biennial Report on Great Lakes Water Quality*, the **International Joint Commission** (IJC) recommended that Lake Superior be designated a demonstration basin to apply a policy of zero point source discharge of persistent toxic substances. With the exception of several localized areas, Lake Superior is recognized as the most pristine of the Great Lakes water bodies. Thus far, incoming pollutants from its relatively few point and nonpoint sources have been greatly diluted in its huge volume. Although a significant portion of the persistent toxic burden arrives via atmospheric deposition (International Joint Commission 1990), certain point sources have caused and continue to cause localized degradation and an increase in the loading of persistent toxic substances.

The zero discharge recommendation, focussing on point sources such as the pulp and paper industry, was the culmination of a longstanding interest in the conventional and toxic discharges from the forest products sector.

In the 1977 Appendix C of the Annual Report of the Remedial Programs Subcommittee to the Implementation Committee, the **Great Lakes Water Quality Board** (WQB) summarized basin loading trends, gave an overview of pulp and paper making processes, and outlined state, provincial and federal initiatives to regulate pulp and paper mill effluent (Great Lakes WQB 1977).

At that time, United States Environmental Protection Agency effluent guidelines focussed on **total suspended solids** (TSS) and **biochemical oxygen demand** (BOD) and reflected adoption of the **best practicable technology** (BPT) for specific mill types. In Canada, regulations and guidelines limited the discharge of TSS, BOD and substances acutely lethal to test fish species. Overall, American BOD standards were approximately three times more restrictive than comparable Canadian standards. Conversely, Canadian TSS limits were three times as stringent as those in the U.S.

In 1981, the Pulp and Paper Point Sources Task Force of the Water Quality Board, in *The Response of the Pulp and Paper Industry in the Great Lakes Basin to Pollution Abatement Programs*, reported on pollution abatement programs, effluent limitations, discharge trends, monitoring practices, and the industry's technological advances in the United States and Canada. The task force found that the industry had made significant reductions in conventional pollutants, yet further reductions were necessary to meet the objectives of the Water Quality Agreement. Moreover, the task force stressed the importance of identifying and removing toxic substances from pulp and paper mill effluent. Of particular concern were persistent and bioaccumulative substances, including chlorinated organic compounds. The task force recommended that practical measures be employed to reduce the production and discharge of these substances. Specifically, industry was encouraged to substitute chlorine dioxide for chlorine (elemental chlorine) bleaching and to improve unbleached pulp washing to minimize the carryover of dissolved organic material into the bleaching process (WQB 1981).

The 1987 Water Quality Board report updated industry progress in reducing conventional pollutants and reviewed acute toxicity testing data from Ontario and Wisconsin mills. From 1980 to 1985, total loadings of TSS and BOD to the Great Lakes basin were reduced by 26% (from 144.5 to 106.2 tonnes/day) and 30% (from 384 to 269 tonnes/day), respectively. Further, pollution abatement at Ontario pulp mills was primarily responsible for these reductions. Further toxicity testing revealed that 14 of 20 Ontario mills had effluent lethal to test species, while that at 8 of 20 Wisconsin mills was lethal. Although the protocol for substantiating ratings of acute toxicity had at the time not been well established, six of the eight lethal mills were categorized as severely toxic (WQB 1987).

In 1989 the Water Quality Board noted that, despite significant reductions of conventional pollutants by the pulp and paper industry, it remained a major contributor of BOD and TSS to the Great Lakes basin. In Ontario, this industrial sector accounted for approximately 80% of all BOD loadings from industrial sources discharging directly into the basin, and exceeded the BOD and TSS discharges from all of the province's municipal treatment plants in the Great Lakes basin. The Board thus recommended that mills adopt secondary treatment or other equivalent pollution abatement technology aimed at reducing levels of conventional and toxic contaminants in effluents from these sources (WQB 1989).

A number of complex organochlorines are contained in bleached pulp and paper effluent, which could pose some hazard to aquatic life forms and remain unidentified. In the absence of an extraordinary effort, it is likely that many of these substances will remain unidentified. The IJC's report, *A Strategy for Virtual Elimination of Persistent Toxic Substances*, released in 1993, recommended that

> "The Parties commission an exhaustive investigation that explores all factors and implications related to the implementation of the proposed sunsetting of a basic feedstock substance such as chlorine."

In response to this particular recommendation, coupled with restrictions on chlorinated organic discharges, particularly dioxin, the pulp and paper industry has begun to modify processes and feedstocks. Most recently the market and associated price for timber products was improved dramatically, allowing for investment in appropriate process modifications. The sustainability of the basin's forest industry is an ongoing interest of the Water Quality Board, which it hopes to comment on in the near future.

1.2.3 Effluent Characterization: Assessing the Potential for Harm

Effluent generated from pulp and paper mills is a complex mixture of components, each with its own characteristics, properties and potential hazards. Collectively these components present a challenge for the establishment of appropriate tests, monitoring procedures and control technologies. The composition of pulp mill effluent is largely dependent on the type of wood used, in-plant processes (including, in some cases, bleaching sequences) and the efficiency of the effluent treatment procedures. Unbleached pulp mill effluent normally contains resin acids and soaps, fatty acids, diterpene alcohols and phytosterols. If chlorine bleaching techniques are used, the effluent contains chlorinated phenols, chlorinated acids, alcohols, aldehydes, ketones and aliphatics as well as aromatic hydrocarbons. Numerous volatile sulphur-containing compounds may also be found in pulp mill effluent (Sprague and Colodey, 1989; Kringstad and Lindstrom, 1984). Chloroform and toluene may also be emitted in vapour form to the atmosphere.

Regulatory guidelines for the discharge of pulp and paper effluent traditionally relied on such quantitative, physical parameters as BOD and TSS. BOD, as an indicator of the presence of organic material, measures the tendency of an effluent to consume dissolved oxygen from a receiving water in the course of natural chemical degradation (Bonsor et al. 1988). Conversely, TSS measures the amount of solid organic matter suspended in water. The slow decomposition of fibrous mats, formed from those suspended organic solids, and other contaminants results in anoxic (oxygen poor) conditions and the formation of toxic gases in the receiving waters (Bonsor et al. 1988). Although these parameters remain integral in the overall assessment and characterization of effluent, the current legislative and scientific thrust is towards more organism-based, sentinel tools for measurement.

Testing, required by such regulatory statutes as the **Canadian Environmental Protection Act** (CEPA), the U.S. EPA's **Clean Water Act** (CWA), and the Province of Ontario's **Municipal/Industrial Strategy for Abatement** (MISA) has moved beyond the single-species acute and chronic toxicity test towards a multi-organism approach, to better represent the complexity of the ecosystem (Cairns 1986). In addition to standard 96-hour LC50 guidelines (to be discussed further), regulatory bodies are incorporating toxicological and histological examinations to ensure that any indicators of stress, particularly those at a biochemical level, are not overlooked. Governing bodies have also increased efforts to monitor contaminants of concern. However, no consensus has been reached as to which parameter, AOX or trace chlorinated organics, better represents the hazard associated with mill effluent.

Acute and Chronic Toxicity Testing

Incorporated into required effluent testing, acute and chronic toxicity tests have evolved from their original design as increased consideration is given to species selection, testing duration and design, and possible sublethal effects.

Toxicity may be assessed on an acute or chronic level. Acute toxicity measures the effect of effluent on lifeforms from short-term exposure leading to a relatively immediate crisis or end point, whereas chronic toxicity measures effects developing after continuous, long-term exposure to low doses of toxic material (Ontario Ministry of Environment 1988). Both acute and chronic toxicity can be manifest in organisms as sublethal or lethal effects. A sublethal effect indicates an impact on a given organism other than death, while lethal effects result in the demise of the organism.

Acute toxicity is generally measured using a 96-hour LC50 test. This test measures the percentage of an effluent, which, when mixed with clean water, causes a 50% lethality to test organisms over a 96-hour period. The lower the effluent percentage, the higher the toxicity (Ontario Ministry of the Environment 1988). For many organisms, the difference between acute lethality and non-lethal concentrations is small. Sudden, subtle fluctuations in whole effluent or individual components at or temporarily above the LC50 could result in the mortality of aquatic organisms in the immediate receiving waters of pulp mill discharges. This testing is often used as a factor in determining receiving water capacity, which assumes that the effluent will be sufficiently diluted upon entering the receiving water, an assumption which is not always met (Servos et al. 1992). Regulations which require "non-lethality at the end-of-pipe" avoid the difficulties inherent in this assumption.

Limitations associated with **Lethal Concentration** (LC) testing include the inability of the experiment to duplicate all possible in situ parameters. Physical changes in temperature, pH and dissolved oxygen levels in receiving waters are among the factors that may affect toxicity evident in the vicinity of the discharge.

Chronic toxicity may be expressed as decreased reproductive performance, biochemical or physiological change, morphological deformities, mutagenicity or carcinogenicity (Environment Canada/Health and Welfare Canada 1991). A chronic toxicity testing protocol is more difficult to design as outcomes are, in most cases, less dramatic than that of the acute procedure. It is therefore essential that more comprehensive monitoring procedures and testing protocol be developed to address this issue. The current pulp and paper regulations under the Canadian Environmental Protection Act of 1991 require testing to determine chronic impacts on early life-stage development of fish, preference/avoidance behaviour in fish, and invertebrate reproduction.

Subtle, sublethal effects which can pass relatively undetected within a population may cause significant harm. Behavioural modifications, which cause an individual to deviate from "normal" patterns, may alienate individuals from the population. In essence, although an individual has not died from exposure to a toxic substance, its inability to perform the appropriate mating ritual means that it cannot reproduce. The same can be said for an individual who fails to recognize danger due to reduced sensory perception. Although direct cause of death was due to predation, a toxic response was a significant contributing factor. These very subtle changes may provide the foundation for a consequential species shift and alteration of the ecosystem over time.

Current acute and chronic testing provides only limited information on potential effluent toxicity. Due to financial and technical constraints, "representative" species are selected from various rungs of the food chain in an attempt to characterize the overall impact on biota. Unfortunately, an effluent's LC_{50} is not a property; it is a biological response by the test organism. Thus estimating through, and extrapolation to, other organisms is significantly limited.

Current legislation requires that toxicity testing be carried out on whole effluent, thereby accounting for any interactions among components. It is difficult to predict the mixture's toxicity on either an acute or chronic scale. Bonsor et al. (1988) attempted to predict the toxicity of bleached mill whole effluent by estimating the contribution of each individual chlorinated organic compound (chlorinated catechols, guaiacols, phenols, resin acids and fatty acids) contributed to the overall toxicity (Environment Canada/ Health and Welfare Canada 1991). Estimates so derived varied from 2.2 to 0.2 times the actual, observed acute lethal level.

Adsorbable Organic Halogens (AOX) vs. Trace Contaminants Analysis

Because of the variable and complex nature of mill effluent, it is unlikely that all chlorinated compounds in bleached pulp mill effluent will ever be identified or adequately quantified (Environment Canada 1991; Bonsor et al. 1988). Therefore, numerous jurisdictions have explored a surrogate means by which the hazard presented by this effluent mixture can be determined.

The Provinces of Ontario, Quebec, Alberta and British Columbia have chosen to regulate the discharge of organochlorines through the use of the sum parameter AOX. This technique involves passing an effluent or wastewater sample through activated carbon to adsorb organic substances. After the carbon is washed to remove inorganic halides it is combusted, and the gaseous products are analyzed for total halogens. In effluent from bleached pulp mills, the halogen (X) component is almost entirely chlorine (Environment Canada 1991).

Because AOX is a non-specific measure of halogenated organics, it does not identify classes of constituent chemicals or individual compounds. Thus the potential toxicity, persistence or bioaccumulative capacity of specific organic substances — and of the total effluent — cannot be derived, and AOX cannot be taken as representative of the relative toxicities of the constituent compounds. For example, mills discharging equal concentrations of AOX may exhibit very different toxicities (as measured by an LC_{50} test) due to the varying proportions of individual components (Holloran et al. 1992). AOX is effective, however, as an indicator of progress towards the virtual elimination of industrially discharged chlorinated organic compounds into the Great Lakes waters.

Environment Canada, along with the U.S. states in the basin, rather than utilize the AOX sum parameter, have adopted monitoring regulations for levels of individual organochlorines of concern. This approach is also favoured by a significant segment of the pulp and paper industry (McCubbin and Folke, 1995), who support regulating specific chemicals of a particularly toxic nature such as dioxins and furans. A limitation to this approach, however, is that only 10-40% of low molecular weight (mwt<1000) chlorinated components in bleached mill effluent have been satisfactorily characterized (Kringstad and Lindstrom, 1984). Because these low molecular weight compounds may present a greater risk due to their ability to cross biological membrane, many unidentified toxic compounds may be released into the environment without specific regulation or control.

An additional method of effluent toxicity assessment has been suggested to compensate for concerns surrounding both the use of AOX and trace contaminants. Through the use of **Toxic Equivalency Factors** (TEFs), the toxicity of the entire AOX mixture may be expressed as a ratio of the individual compound (or group) toxicity to the toxicity of a reference compound from the group. A specific application of this principle is the generation of **Pentachlorophenol Toxicity Equivalents** (P-TEQ) (Holloran et al. 1992). A similar technique has been utilized to equate total PCB congener content in fish and mussel fillets to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin expressed in terms of TCDD-Equivalents (TCDD-EQ) (Williams et al. 1992; Hong et al. 1992). This technique would require more extensive differentiation of effluent components than the AOX sum parameter provides — specifically to break the components into families or groups — but would provide more accurate estimates of the total effluent toxicity than individual trace contaminant analysis may reveal. Table 1 expresses the toxicity of pulp mill effluent, from facilities which utilize chlorine processes, in terms of their **Toxic Equivalents** (TEQ).

Any technique chosen to characterize effluent toxicity, be it AOX, trace contaminant analysis or TEFs, must be sufficiently conservative to compensate for the various routes of exposure of each organism. Although effluent may be released at a "no observable adverse effects level" (NOAEL), organisms with specific lifestyle traits (i.e. benthic feeders) may be at a significantly greater risk of stress due to unique exposure dynamics than an organism with a different lifestyle.

Dioxins and Furans

The term "dioxin" commonly refers to a family of 210 structurally related chlorinated aromatic compounds, known as **chlorinated dibenzo-*p*-dioxins** (CDDs) and **chlorinated dibenzofurans** (CDFs). Dioxin toxicity is enhanced by the substituion of chlorine molecules in the 2,3,7 and 8 positions. The most toxic member of this family is 2,3,7,8-TCDD which is among the most potent toxicants known and a suspected carcinogen. Other potentially harmful dioxins and furans have the characteristic 2,3,7,8-substitu-

Table 1.

Estimated Contributions of PCDD/PCDF to the Great Lakes in 1993 from Liquid Effluent from Direct Discharging Pulp and Paper Mills Which Utilize Chlorine-Containing Compounds in Their Processes (n)

Company	City	State or Prov.	Lake	Estimated Water Transfer Coefficient for PCDD/F (see note a)	Estimated contribution of PCDD/PCDF to Lake (g TEQ/yr) (see notes b and c)			Notes	# of actual samples on which estimate is based
					minimum	medium	maximum		
E.B. Eddy	Espanola	ON	Huron	100%	0.0560	0.1010	0.1460	e	7
Thorold Specialty Papers	Thorold	ON	Ontario	75%	0.0004	0.0104	0.0205	e	5
Mead	Escanaba	MI	Michigan	100%	0.0133	0.0368	0.0629	d,g	6
Champion International	Quinnesec	MI	Michigan	75%	0.0119	0.0237	0.0475	h	0
Badger Paper Mills	Peshtigo	WI	Michigan	100%	0.0000	0.0041	0.0083	d,i	2
Wisconsin Tissue Mills	Menasha	WI	Michigan	75%	0.0000	0.0064	0.0127	d	1
Fort Howard	Green Bay	WI	Michigan	100%	0.0012	0.0211	0.0409	d	4
P.H. Glatfelter	Neenah	WI	Michigan	75%	0.0000	0.0042	0.0084	d	1
Scott Paper	Oconto Falls	WI	Michigan	75%	0.0000	0.0009	0.0019	d,k	1
James River	Ashland	WI	Superior	100%	0.0000	0.0029	0.0058	d,l	1
Avenor	Thunder Bay	ON	Superior	100%	0.0551	0.1281	0.2011	e	11
James River	Marathon	ON	Superior	100%	0.0016	0.0356	0.0696	e	9
Kimberly-Clark	Terrace Bay	ON	Superior	100%	0.3372	0.4174	0.4977	e,m	12
				TOTAL	0.4767	0.7926	1.1233		

(a) The water transfer coefficient (WTC) is the fraction of the PCDD/F discharged from the plant that is estimated to be transported to one of the Great Lakes. For direct discharge to one of the lakes or a tributary within a few miles of the lake, the WTC is assumed to be 100%. If the effluent is discharged to a tributary at a point more distant from the lake, the WTC is assumed to be reduced by 25%.

(b) For all estimates, the basic methodology was to multiply the appropriate flow rate of the liquid effluent stream by the measured or estimated concentration of PCDD/F in the effluent. The minimum annual estimated discharge amount was calculated by assuming that all non-detects were zero; the medium estimated discharge amount was determined by assuming all non-detects were at one-half the detection limit; and the maximum estimated discharge amount was calculated by assuming that all non-detects were at the reported detection limit of the measurement.

(c) The estimates of PCDD/F discharge were calculated using only the available data for 2,3,7,8-TCDD (with a toxic equivalency of 1) and 2,3,7,8-TCDF (with an assumed toxic equivalency of 0.1). These were the only two congeners for which data were available for the U.S. pulp and paper mills, and these two congeners are believed to contribute the majority of the PCDD/F toxic equivalents in mill effluents. Data from Canadian mills showed that other congeners were occasionally detected in effluent, and did, in some cases, add significantly to the toxic equivalents in the discharge.

(d) The estimate of PCDD/F discharged from the mill was based on data supplied to CBNS by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI).

(e) The estimate of PCDD/F discharged from the mill was based on data supplied to CBNS by the Ontario Forest Industries Association.

(g) The measured concentration of PCDD/F and the flow rate of the bleach plant effluent were used to make the discharge estimate, rather than the comparable parameters in the final effluent. When the final effluent has concentrations of dioxins and furans that are less than the detection limit, this may be a more accurate procedure to estimate the plant's emissions.

(h) Estimated by CBNS based on data from similar plants.

(i) No data for 1993 were available; data from 1992 and 1994 were averaged to estimate the 1993 discharge.

(k) 2,3,7,8-TCDF was not measured; it was assumed to be present at less than the detection limit of 1.6 pg/L which was reported for the measurement of 2,3,7,8-TCDD at this point.

(l) No data for 1993 were available; data from 1991 were used.

(m) The company has stated that their research identified a contaminated sewage pipe as the primary source of PCDD/F in their discharge. They replaced the pipe in April 1994, and effluent samples taken since then have indeed shown decreased levels of PCDD/F. In 8 samples taken from May 1994 to Dec 1994, the PCDD/F levels in the effluent (considering only 2,3,7,8,-TCDD and 2,3,7,8-TCDF as with all the other plants) correspond to an annual medium-estimate loading of approximately 0.096 g TEQ/yr.

(n) Only pulp and paper mills which use chlorine-containing compounds in their processes (e.g. chlorine, chlorine dioxide, sodium hypochlorite) have been included in this list. Some of the facilities on this list have reported process changes and/or effluent data which suggest that PCDD/F discharges have decreased since 1993.

Adapted from Cohen et al. (1995)

tion, however have additional chlorines in their structure (penta-, hexa-, hepta-, and octa-CDD/Fs). Accordingly, the toxicities of other dioxins are expressed in relation to 2,3,7,8-TCDD by using a Toxicity Equivalency Factor (TEF) described above (Bonsor et al. 1988). 2,3,7,8-TCDD has an assigned TEF of 1.0. The closely related compound 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is estimated to be one-tenth as potent as 2,3,7,8-TCDD; therefore, it has a TEF of 0.1. Although other dioxins have been measured in mill effluent, the pronounced toxicity of TCDD and TCDF has set them apart as important contaminants for study and regulation.

Table 1 contains 1993 toxicity estimates for pulp and paper mills which utilize chlorine processes. Mills which do not use chlorine-containing compounds (such as elemental chlorine, chlorine dioxide, or sodium hypochlorite) were not solicited for the "Quantitative Estimation of the Entry of Dioxins, Furans and Hexachlorobenzene into the Great Lakes From Airborne and Waterborne Sources" report, by Cohen et al. (1995) as they are not considered to be significant sources of dioxins and furans. This table was modified to include only those mills whose effluent is directly discharged to either one of the Great Lakes or a tributary thereof. Mills whose effluent is discharged to municipal sewage treatment plants were not considered within the scope of this chapter.

Data were provided to the Center for the Biology of Natural Systems (Queens College, CUNY) for inclusion in the Cohen et al. report by the **National Council for Air and Stream Improvement, Inc.** (NCASI) and the Ontario Forest Industries Association.

Prior to inclusion of Table 1 in this report, steps were taken to corroborate the data with several government sources. On the advice of the U.S. EPA, a search of the **Permit Compliance System** (PCS) was completed. A search for 1993-1995 data on the eight U.S. mills which are contained in Table 1 revealed 68 "No Data" entries, 2 "No Data Violation" entries, 9 "Less Than Average Maximum" values, and 1 "No Monitoring Required" status entry. Thus, no direct verification of the NCASI values was possible.

The State of Wisconsin was subsequently solicited for their assistance with the Wisconsin mill data. Because their permitting system requires monitoring only if results from analytical test during permit reapplication indicate the potential for exceedence of water quality based guidelines, limited data were available. However, their records indicate that no detectable level of 2,3,7,8-dioxin congeners have occurred in the effluent of Wisconsin mills since approximately 1989.

As mills are required to monitor and report effluent data under the Canadian Environmental Protection Act, the Ontario Forest Industries Association data were sent to Environment Canada for their scrutiny. Overall, staff felt that the data were representative of their records. Dioxin data for 1994 and the beginning of 1995 for Canadian mills were available, however as no equivalent U.S. data were available, those figures are not presented.

As footnote "c" in Table 1 indicates, TEQ values are estimated from 2,3,7,8-TCDD and 2,3,7,8-TCDF data only. Because the original submission from the Ontario Forest Industries Association was based on all dioxin congeners, and subsequently corrected to match the NCASI submission (which based TEQ estimates on the tetra (four) chlorine, 2,3,7,8 substituted congeners of dioxin and furan only), TEQ loadings to the lakes appear lower than their actual magnitude. In some cases, the TEQs provided by Ontario decreased by 50% when the contribution of congeners other than 2,3,7,8-TCDD/F was discounted. This suggests that the contribution of 2,3,7,8-substituted dioxin and furan congeners, other than the tetra form, may have a significant impact on effluent TEQ estimates. This result differs from the conclusion which was drawn from the joint *U.S. EPA/ Paper Industry Cooperative Dioxin Study - "The 104 Mills Study"* (1990). This report analyzed 10 bleached pulps, 9 wastewater sludges and 9 final wastewater effluents. The U.S. EPA concluded that "even with the most conservative assumptions, that 2,3,7,8-TCDD and 2,3,7,8-TCDF account for the vast majority of the 2,3,7,8-TEC (Toxic Equivalent Concentrations) in each sample."

It must be noted that Table 1 does not represent the output of a single initiative or program to determine the toxic contributions associated with dioxin and furan discharges from pulp and paper mills using chlorine-containing compounds. Rather, it is a compilation of data from various sources offered in a very broad context. The intent behind its inclusions is to provide a preliminary estimate of these discharges and thus encourage the preparation of more precise, tightly constrained and specific tabulation of such data in the near future.

Dioxin is extremely toxic and lethal to some test animals at low concentrations. Studies conducted on rainbow trout suggest that TCDD and TCDF can cause mortality, reduced growth and abnormal behaviour during the fish's early life stages. The 56-day LC_{50} of 2,3,7,8-TCDD for rainbow trout was measured at 0.046 ppt (part per trillion) and the lowest concentration tested, 0.038 ppt, displayed some effects of chronic toxicity by affecting growth (Bonsor et al. 1988).

Dioxins are sparingly soluble in water, persistent in soils and sediment, and readily bioaccumulated in fish. Once sorbed to soil particles, the main transport mechanisms for these compounds appear to be through erosion and the aquatic transport of sediments. The only environmentally significant path of destruction for dioxins and furans is photodechlorination, a process requiring the presence of another material capable of donating hydrogen atoms (Bonsor et al. 1988). Such a process can occur under the extreme thermal oxidation conditions present during incineration.

Recent technological steps taken by the pulp and paper industry have significantly reduced the discharge of dioxin in wastewater streams. Most significantly new technologies, particularly those which utilize hydrogen peroxide, ozone, oxygen, and/or chlorine dioxide substitution, are replacing elemental chlorine bleaching processes (Business and the Environment 1995); the non-chlorinated processes should eliminate production of dioxin in the process entirely.

Mixed-Function Oxygenase (MFO) Induction Testing

Recently the effect of pulp mill effluent on the **mixed-function oxygenase** (MFO) enzyme system in fish has come under close scrutiny, particularly by the Canadian Departments of the Environment and Fisheries and Oceans. The MFO enzyme system is a key detoxification process in fish, which operates on the smooth endoplasmic reticulum in hepatocytes (liver cells). This general term refers to the function of all hepatic detoxification enzymes collectively. Through MFO action, potentially harmful compounds that enter the body are structurally altered, thereby making it possible for the kidney to remove them. The reaction responsible for this change is known as hydroxylation and involves the addition of an OH- group to the compound, rendering it water soluble. In many cases this is an effective mechanism for the removal of anthropogenic substances from the body without harm. There is, however, the possibility that the conversion may also lead to the formation of an "active" or more dangerous form of the substance (as is the case in many cancers) or that the water solubility of the substance may allow it to rapidly cross biological membranes and cause more immediate, or acute, complications (Becker and Deamer, 1991).

Under normal conditions, the MFO system operates continuously. Activity level fluctuates depending on such environmental and physiological factors as seasonal temperature and reproductive state of the individuals (i.e. spawning) (Jimenez et al. 1990, in McCarthy and Shugart). Variation has also been discovered between the two sexes and members of various species (Munkittrick et al. 1994).

Researchers have found, however, that fish within an area of pulp mill effluent outflow may exhibit increased MFO activity, possibly as much as 20 times greater than normally expected (Munkittrick et al. 1992). This is attributed to the increased influx of potentially dangerous chemicals that the body must attempt to remove to maintain normal function. To exemplify this, Munkittrick et al. (1992) conducted a study before and after a mill maintenance shutdown, paying particular attention to MFO levels. A significant decrease in MFO activity following the halt of effluent outflow was noted, indicating the stress on the population had been removed. The enzyme system could operate at a lower level as it did not need to compensate for the excess chemical substance which was introduced by the effluent. No direct consequence of elevated MFO enzyme induction has been conclusively determined (Munkittrick et al. 1994); however, Okey (1990) suggested a possible correlation between increased MFO induction and reproductive abnormalities found in fish populations.

A specific MFO enzyme called **7-ethoxyresorufin-O-deethylase** (EROD) is often measured as an overall estimate of the MFO induction level. A study conducted on the Spanish River in Ontario by Servos et al. (1992) found increased EROD induction in white suckers downstream of the effluent outflow from a modernized bleach process pulp mill (i.e. chlorine dioxide substitution, oxygen delignification). Comparatively, the upstream reference sites showed significantly lower levels of EROD activity. This indicates that a factor in the effluent is placing a chemical stress on the population, thereby initiating detoxification mechanisms. Munkittrick et al. (1992), in their pre- and post-mill shutdown study, found no sign of EROD induction during the shutdown, although significant induction had been observed prior to plant shutdown. Interestingly, although the specific effluent component responsible for the induction of EROD activity has not been identified, research has shown no correlation between the level of EROD induction and the sum parameter AOX (Swanson et al. 1992). Munkittrick et al. (1994) supported this conclusion with their observation that EROD induction in white suckers occurred downstream of effluent outflow from both bleaching and non-bleaching facilities.

MFO induction provides a sentinel, early warning indication that a stress has been placed on a population; however, because no single component or components of mill effluent has been identified as the causative agent(s) of this stress, it is impossible to determine what technical modifications are necessary in the pulping/bleaching processes to curtail it. Specifically, it is difficult to gauge the success of abatement programs, including installation of secondary treatment, based on MFO induction levels. The characteristics of the stressing chemical, primarily it's degree of hydrophobicity (desire to leave the water stage), further obscure its identification.

Ultimately, the causative agent(s) may be either hydrophillic (water soluble) or hydrophobic (water repelling). Hydrophillic compounds may be quickly released from the organism, therefore demonstrating a rapid reduction in the MFO level if discharges cease. Conversely, a hydrophobic chemical stressor is not easily depurated once it has entered the fish. Therefore, even if treatment or process changes are successful in restricting such discharges, the MFO system may still exhibit elevated levels for some time. Effluent components may sorb to adjacent sediment and exhibit long-lasting effects even after their discharge is ceased. There is a strong possibility that a hydrophobic chemical agent could yield a "false negative," i.e. it could appear that treatment or process changes were not successful in removing the responsible substance, although it had in fact done so.

A study conducted at Jackfish Bay, Ontario by Munkittrick et al. (1992), before and after the installation of secondary effluent treatment, exemplified the difficulties involved in characterizing the causative agent. Following two years of secondary treatment operation, no net reduction in MFO activity was apparent in the population. Assuming a single agent (or single family of compounds) was the causative agent, this finding initially suggested that the stressor was hydrophobic in nature and a sediment "store" was responsible for the maintenance of high levels. However, the same population demonstrated *normal* MFO levels *after a plant* shutdown, indicating that the compound may well be hydrophillic and that secondary treatment had been ineffective in removing the stressor. Until such time as the stressing agent is identified, the complexity of effluent chemical mixtures allows only for limited conclusions.

Although nonspecific, MFO induction appears to have value in determining the potential harm attributable to pulp mill effluent. Determination of a more specific agent and assessment of the relative impact and significance of this stress is necessary to determine what corrective or rehabilitative steps may be required to improve the health of the system.

1.2.4 Pulping and Bleaching Technology

The components of pulp mill effluent, and subsequently the toxicity of the mixture, is related to the pulping and bleaching mechanism employed by the facility. Figure 2 provides a skeleton of the pulp and paper process.

Pulping Technology

In general, the objective of the pulping process is to separate the desirable cellulose fibres from other wood components such as lignin and hemicellulose. Hemicellulose surrounds the cellulose fibres, intruding into their pores like a glue between the cellulose and overlaying layer, lignin. Lignin is a complex molecule which surrounds and strengthens the cellulose-hemicellulose structure. Its degradation results in the release of phenol-based compounds, one of the toxic constituents in effluent.

Pulping, which is preceded by mechanical or chemical debarking, cleaning and chipping of the timber (Kringstad and Lindstrom, 1984), may be completed by means of a kraft, mechanical, chemimechanical, thermomechanical or chemithermomechanical process.

Kraft Pulping

Kraft mills employ chemical processes to detach cellulose fibres and dissolve lignin. Wood chips are initially steamed to heat the fragments and fill internal air spaces with water vapour. Kraft pulping liquor, composed of sodium hydroxide (NaOH) and sodium sulfide (Na2S), cleaves ether bonds in the lignin (Kringstad and Lindstrom, 1984), resulting in its degradation during the cooking process. Following this, the application of air under pressure is used to fully separate chips into fibres (Tappi Press 1993).

Mechanical Pulping

Mechanical groundwood pulping physically breaks down the wood to a fibrous state via grinding and chopping. Roughly 90% of wood introduced into the systems becomes part of the resultant pulp. Due to the intense physical conditions, mechanical breakdown of the wood often damages a portion of the cellulose fibres (Madore 1992).

Chemi or Thermomechanical Pulping

Chemi or thermomechanical plants use the manipulation of either chemical or thermal, and mechanical factors to maximize the amount of cellulose released from wood. Some facilities utilize chemical, thermal and mechanical factors throughout their processes. These are referred to as chemithermomechanical plants.

Bleaching Technology

Following pulping, whether by chemical, mechanical or chemithermomechanical means, the pulp fibres are often bleached to meet consumer fine-paper brightness demands.

Entering the bleaching stage, between 5-10% of the original lignin remains (Bonsor et. al. 1988). Because of its natural colour, which subsequently darkens over time, the lignin must be decoloured to ensure prolonged paper strength, stability and brightness. Delignifiers, such as oxygen and chlorine, may be used to further degrade the lignin in unbleached pulp without damaging the cellulose structure (Bettis 1991, in Patrick). This results in a significant increase in paper whiteness and strength; however, quantifiable levels of persistent and bioaccumulative chlorinated organic compounds may be detected after the use of specific bleaching techniques.

Elemental Chlorine

Although common in the past, the use of molecular chlorine bleaching has significantly decreased with the onset of governmental regulations and environmental concerns over the possible adverse effects of dioxins and furans. The detection of dioxins and furans in effluent streams fostered the use of alternate technologies that utilize chlorine dioxide, oxygen, or hydrogen peroxide bleaching.

Chlorine Dioxide

Substitution of chlorine dioxide for molecular chlorine has occurred in many pulp bleaching facilities, both in Canada and the United States. Varying degrees of substitution have been reached, although numerous facilities have moved towards, or achieved, 100% chlorine dioxide substitution. Chlorine dioxide operations require less bleaching solvent to degrade the lignin than do elemental chlorine facilities, and also reduce the generation of harmful bioaccumulative organochlorines.

Oxygen Delignification

Oxygen delignification requires oxygen gas, sodium hydroxide, high pressure and high temperatures. It is most effective as a supplementary stage before chlorine or chloride dioxide bleaching operations. Approximately half the nor-

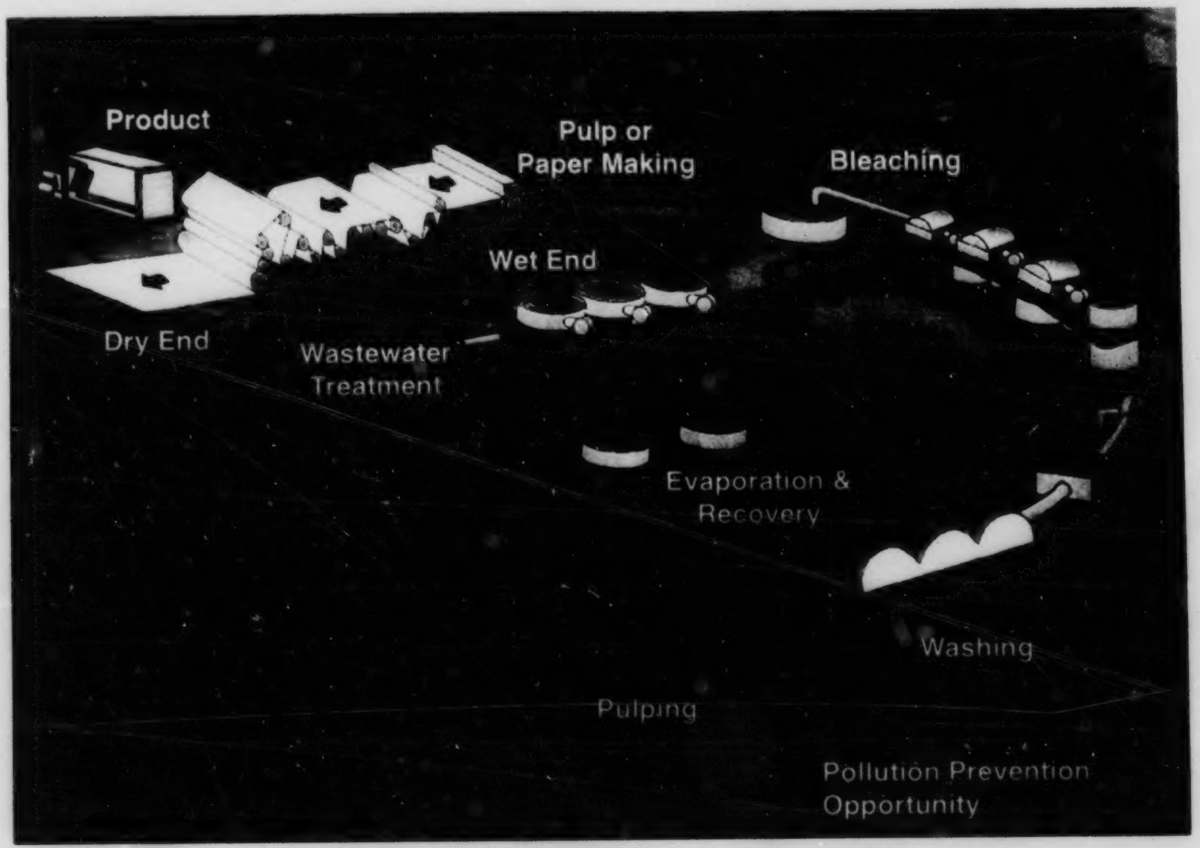


Figure 2. Pulp and Paper Process Overview (Source: Office of Water, U.S. EPA)

mal amount of bleaching chlorine is needed when oxygen delignification is incorporated.

Hydrogen Peroxide

Rather than undergo chlorine bleaching, mechanically and chemically generated pulps are often treated with hydrogen peroxide (Brooks et al. 1994; ChemInfo 1994). This bleaching method produces a high quality, bright product (Strunk 1991, in Patrick) acceptable by consumer standards.

Ozone

Ozone bleaching may be used as an alternative to hydrogen peroxide, although it must be preceded by oxygen delignification. Oxygen gas is recovered in a gas recycling system, and that which is not completely expended during this process may be transferred back into the oxygen delignification procedure for reuse (Shackford 1991, in Patrick).

1.2.5 Implementing Technology to Meet Present and Anticipated Environmental Regulations

Many companies in the pulp and paper industry have developed technology to meet the requirements of present and future environmental standards. "Anticipation of the extent, rather than the direction of future environmental regulations, has been a major driving force behind novel chemical pulping technologies during the past 10 years" (Lora and Pye, 1995). With the establishment of secondary treatment throughout the basin, engineers and designers have re-evaluated operations and established new technologies that should address environmental concerns while maintaining suitable product quality. Most existing facilities have moved towards **Elemental Chlorine Free** (ECF) and **Totally Chlorine Free** (TCF) bleaching processes, while others have chosen to confront the development of an **Effluent Free Mill** (EFM) or **Totally Effluent Free** (TEF) mill.

Elemental Chlorine Free (ECF) Bleaching

ECF technology is employed primarily by existing facilities upgrading to meet environmental standards. It is generally accepted that the designers of new mills will be looking beyond ECF processes, towards TCF or EFM standards.

The use of **chlorine dioxide** (ClO_2) in place of **elemental chlorine** (Cl_2) in the bleaching process is perhaps the most well established mechanism to reduce the quantity of chlorinated organics released in mill effluent. Because chlorinated organic compounds (AOX) formation is directly proportional to the consumption of elemental chlorine, the substitution of ClO_2 for Cl2 decreases the amount of available reactive chlorine, and therefore the AOX quantity generated (Graves et al. 1993). Used alone, 100% chlorine dioxide substitution resulted in an 80% decrease in total AOX, a 42% reduction in BOD, 62% less generated colour and a 60% decrease in toxicity (Graves et al. 1993).

The **Bleach Filtrate Recycle** (BFR) Process, developed by Champion International, uses chlorine dioxide bleaching in addition to the recovery of chlorine filtrates through the use of a conventional kraft recovery system (Canovas and Maples, 1995). An 86% decrease in AOX release, and 72% reduction in effluent BOD are a result of this recovery process, with approximately 91% of all AOX generated in brownstock washing destroyed before it reaches the recovery boiler (Canovas and Maples, 1995).

Other innovative technology includes oxygen delignification, or oxygen prebleaching, which occurs during the pulping portion of the process. Converting the glue-like lignin into a soluble compound, it reduces the need for chemical treatments for the same purpose. Its role in the reduction in AOX results from its removal of organics that would have otherwise been able to participate in chlorine substitution reactions (Dence and Annergren, 1979). Alone, oxygen delignification has been found to reduce AOX by 41% (Graves et al. 1993), however its combination with other technological advances has been found by Swedish mills to reduce AOX while increasing the efficiency of the mill process (Meadows 1995a).

Outside actual substitution efforts, Alcell Technologies Inc. has developed an "organosolv" process to modify raw pulp to a form that has increased bleachability and increased sensitivity to oxygen delignification (Lora and Pye, 1995).

Totally Chlorine Free (TCF) Bleaching

Albert (1994a) reflects the sentiment of many industrial officials, stating, "It is no longer of question of whether a totally chlorine free process will replace chlorine-based bleaching as the dominant bleaching technology. The only unknown is when will this happen and what will be the rate of change." This is echoed by Lora and Pye (1995), who consider uncertain future environmental regulations, customer requirements, and the concerns of suppliers of risk capital to be the driving forces behind the incorporation of the latest TCF bleaching process into new kraft mill design.

Bleaching, lacking chlorine in any form, may involve the use of such alternate compounds as **hydrogen peroxide** (H_2O_2), **ozone** (O_3), or **peracids** (general designation, Å). Hydrogen peroxide bleaching is, however, more expensive then a ECF (chlorine dioxide substitution) process, costing an additional U.S. $26-29 per **air dried metric ton** (a.d. ton). These additional costs incurred throughout the entire process (i.e. generation of materials) are offset to some extent by a $5/a.d. ton savings as a result of decreased chemical makeup costs (Brooks et al. 1994). The benefits gained from process changes, safer operations, decreased corrosion of equipment, decreased environmental impact, the competitive advantage of integrating TCF technology, and the advanced preparation for possible future environmental regulations will result in benefits not considered in the study.

The use of ozone bleaching, in conjunction with hydrogen peroxide bleaching, could result in a net savings of $3/a.d. ton (Brooks et al. 1994), thus narrowing this difference to some extent. Ozone has also been utilized independently, with the first ozone bleaching mill operating successfully in Sweden (Meadows 1995b). Internationally, there are eight ozone-bleaching pulp mills, of which seven are TCF (Albert 1994a).

Because conversion to ozone bleaching is initially an expensive capital venture, the use of peracids is being investigated. Although several limitations in the use of peracids have been identified (i.e. the necessity to carefully regulate pH, poor selectivity, expensive on-site generation and associated safety problems), it has been suggested as a viable "intermediate" or transition technology. Companies wishing to postpone significant capital spending may use peracid bleaching until TCF technology development has been further advanced (Ricketts 1995).

Effluent Free Mill (EFM)

The fundamentals of pollution prevention suggest that an effluent free mill will undoubtedly be the future goal for this industry in the developed world. Strategists agree that the development of EFMs will not be limited by technology so much as on economics and management techniques. "Closed-cycle mills, by the year 2000, will not be unduly technologically constrained, but rather will be limited by more organizational factors and business needs" (Patrick et al. 1994). The technology, according to Albert (1994b), already exists for the establishment of EFMs and has, in fact, been successfully implemented at such facilities as Louisiana-Pacific Canada's Chetwynd mill in Chetwynd, British Colombia (Young 1994), and Millar Western Pulp Ltd.'s Meadow Lake Mill in Beaver River, Saskatchewan (Fosberg and Sweet, 1994).

The foundation of a **zero effluent mill** (ZEM) rests on an efficient recovery system. Current recovery systems primarily utilize evaporation, although crystallization technology may possess future potential (Kohler 1994). Integration of evaporation with several non-chlorine pulping techniques may lead to the successful development of a zero effluent bleached kraft mill (Albert 1994b).

The Meadow Lake Mill in Saskatchewan, a TCF system, utilizes hydrogen peroxide in its bleaching process. Vapor compression evaporators serve as its water recovery system. Water use, as compared to a conventional bleached chemithermomechanical pulp mill, is reduced from 568 m^3/hr to 68 m^3/hr, an eight-fold decrease. The efficient recovery of water results in a net reuse of 391 m^3/hr out of the total 400 m^3/hr of effluent sent to the system. Solid waste, which is collected from the effluent, is burned in the boiler. The smelt is then cast into ingots and stored onsite for future chemical recovery (Fosberg and Sweet, 1994). The result is zero liquid effluent release to the environment.

Presently, mechanical vapor recompression evaporators (similar to those at Meadow Lake Mill) are used at the Chetwynd, British Colombia facility, although the plant began its zero effluent operation with the process of freeze crystallization. Three problems prompted the conversion: the crystals were difficult to separate from the effluent until an additional mechanical component was installed; tubes often became clogged with ice due to the increased rate of heat transfer and subsequent degradation in crystal size; and finally, the presence of carbon dioxide aided in the unexpected and unwanted precipitation of calcium carbonate in the crystallizer tubes (Young 1994).

Although no pioneer bleached kraft EFM exist, Albert (1994b) speculates that current technology will provide the framework for its development. A model mill would incorporate evaporization, recovery and oxygen delignification in its processes. A cost assessment revealed that a TCF-EFM (effluent free, totally chlorine free) bleached kraft operation would cost $40 million less than a new ECF bleached kraft mill. In addition, once the capital expenditure has been made, the mill will cost $35/ton less than a TCF-EFM bleached kraft facility producing paper of a similar quality and strength (Albert 1994b).

1.2.6 Discharges - Performance and Improvements

Updated information on compliance, both in the U.S. and Canada, is needed to provide an accurate picture of progress towards the regulatory requirements.

Table 2 is current as of 1992 data, the most recent basinwide data available for U.S. and Canadian sources through the U.S. EPA Permit Compliance System. It does not reflect the significant reductions that have occurred or will occur by the end of 1995, when all Canadian mills should have secondary effluent treatment or equivalent in place.

1.2.7 Findings

- The focus on the industry had shifted from control of BOD (biochemical oxygen demand), TSS (total suspended solids) and acute toxicity to the tracking of dioxin, dibenzofurans and AOX (adsorbable organic halogens) and now to pursuit of biomarkers such as sublethal reproductive impacts, stimulation of liver enzymes (EROD) and a search for more such indicators. These developments parallel the Commission explorations of the past several years.
- These latter phenomena appear to be stimulated by the pulping process generally and do not appear confined to the bleached kraft mills. Attribution of cause, including identification of a particular causative agent or contaminant, continues to be problematic.
- Notwithstanding this evolutionary process, the above indicators retain some relevance in the pulp-producing countries.
- As advocated by the Water Quality Board in the early and mid 1980s, the industry in the Great Lakes basin has largely completed a transition to secondary effluent treatment and use of chlorine dioxide rather than chlorine gas in bleaching. Effluent acute toxicity effects have been largely eliminated and dioxin in effluent has been substantially reduced.
- The alteration in bleaching technology indicates that this industry is applying a pollution prevention rather than a pollution control approach. This former approach will be further reflected in other process changes, including use of ozone and hydrogen peroxide in bleaching, closed bleaching cycles, oxygen delignification and, ultimately, the Totally Effluent Free (TEF) mill.
- The Government of Canada has entered into a five-year joint venture with the industry to investigate closed mill technology. Swedish industry appears to be moving in this direction as well. Total waste management, particularly that in gaseous or solid form, must be carefully considered in the Total Effluent Free mill.
- There is a need to move to 'integrated monitoring,' 'biomarkers,' 'bioindicators' and similar environmental tracking devices. While some have been developed, their evolution to routine application will be a significant challenge.

1.2.8 Recommendation

Given the evolution in the pulp and paper sector from pollution control toward pollution prevention, from conventional single indicators of effluent quality to consideration of more complex bioindicators in adjacent ecosystems, the move by some regulators to a multimedia "cluster" approach, the extent of ongoing research into bioindicators and emerging technologies, and concerns over the sustainability of the forestry, the Parties should prepare a joint report under SOLEC further delineating the status and direction of this industrial sector.

Table 2.
Conventional Pulp and Paper Pollution Discharges to the Great Lakes Basin

				Average BOD (T/D)		Average TSS (T/D)		Average Flow (1000m3/D)	
	Receiving Water	**Facility Name**	**City**	**1987**	**1992**	**1987**	**1992**	**1987**	**1992**
	Lake Erie								
1	Chagrin River	Chase Bag Co.	Chagrin Falls	.04	.10	.02	.04	2.70	1.13
2	Black River	Port Huron Paper Co.	Port Huron	.54	1.04	.35	.33	24.50	14.30
3	Raisin River	Simplex Industries	Palmyra	.04		.06		.90	
4	Lake Erie	U.S. Gypsum Co.	Gypsum	.04	.49	.35	.10	7.30	5.12
5	St. Clair River	James River Corp.	Port Huron	NA	.27	NA	.26	NA	9.19
			TOTALS	**.66**	**1.90**	**.78**	**.73**	**35.40**	**29.74**
	Lake Huron								
6	Thunder Bay River	Abitibi Corp.	Alpena	1.41	1.12	4.24	4.64	7.20	5.15
7	Spanish River	E.B. Eddy Forest Prods.	Espanola	1.83	2.15	4.51	3.59	115.50	119.11
8	Thunder Bay River	Fletcher Paper Co.	Alpena	.32	.23	.07	.07	3.80	2.19
9	French River	MacMillan-Bloedel Ltd.	Sturgeon Falls	37.05	20.56	2.37	2.58	11.90	9.73
10	Cheboygan River	Proctor & Gamble Paper	Cheboygan	.03	.002	.02	.002	4.60	1.51
11	St. Mary's River	St. Mary's Paper	Sault Ste. Marie	2.96	5.50	3.45	2.66	26.90	28.01
			TOTALS	**43.60**	**29.562**	**14.66**	**13.542**	**169.90**	**165.70**
	Lake Michigan								
12	Portage Creek	Performance Papers	Kalamazoo	.23	closed	.02	closed	1.50	closed
13	Fox River	Appleton Papers	Combined Locks	.30	.48	.25	.47	21.00	19.61
14	Peshtigo	Badger Paper Mills	Peshtigo	.31	.47	.08	.20	5.80	7.69
15	Lake Butte des Morts	P.H. Glatfetter Co.	Neenah	.34	.55	.47	.62	14.50	16.84
16	Kalamazoo River	James River Corp. KVP Group	Kalamazoo	.17	.42	.24	.27	15.80	15.89
17	Menominee River	Champion International	Quinnesec	1.25	.22	2.64	2.64	48.40	57.04
18	Fox River	Fort Howard Paper Company	Green Bay	1.70	.84	1.28	1.24	46.00	60.86
19	St. Joseph River	French Paper Co.	Niles	.12	.14	.10	.09	1.90	1.59
20	Fox River	Green Bay Packaging	Green Bay	.36	.29	.39	.19	7.40	6.21
21	Fox River	National-American Can Corp.	Green Bay	.87	.75	.92	.55	38.20	30.55
22	Fox River	Riverside Paper Corp.	Appleton	1.08	1.71	.91	2.26	7.80	7.79
23	Little L. Butte des Morts	Kimberly-Clark Corp.	Neenah	.25	.30	.02	.02	7.50	8.11
24	Fox River	Kimberly-Clark Corp.	Neenah	.03	.16	.07	.12	12.30	13.67
25	Manistique River	Manistique Pulp and Paper	Manistique	.88	.88	2.49	1.38	13.80	18.45
26	Escanaba River	Mead Corp.-Escanaba Paper	Escanaba	1.01	1.37	3.13	2.44	131.30	131.34
27	Kalamazoo River	Mead Corp.-Otsego Mill	Otsego	.10	.18	.08	.17	1.50	1.21
28	Kalamazoo River	Menasha Corp.	Otsego	.05	.77	.02	1.26	2.00	6.06
29	Menominee River	Menominee Paper Corp.	Menominee	1.05	.08	.15	.12	1.20	2.95
30	Fox River	Midtec Paper Corp.	Kimberly	.64	.58	1.18	.58	40.70	45.47
31	Menominee River	Niagara of Wisconsin	Niagara	.89	1.35	1.28	1.14	21.00	22.61
32	Fox River	Nicolet Paper Co.	DePere	.78	.93	.24	.29	11.90	9.61
33	Lake Michigan	Packaging Corp. of America	Filer City	.19	.23	.48	.51	20.30	20.07
34	Kalamazoo River	Plainwell Paper Co.	Plainwell	.13	.09	.19	.15	9.20	9.48
35	Fox River	Proctor & Gamble Paper	Green Bay	.56	.20	1.08	.15	17.40	9.32
36	Menominee River	Scott Paper Co.	Marinette	.78	.73	.65	.29	22.00	16.12
37	Oconto River	Scott Paper Co.	Oconto Falls	.35	.31	.23	.20	4.90	5.52
38	Wolf River	Shawano Paper Mills	Shawano	.40	.52	.12	.08	6.60	6.65
39	Fox River	Thilmany Pulp & Paper Co.	Kaukauna	.70	.76	2.22	1.04	71.40	66.87

Table 2, continued.
Conventional Pulp and Paper Pollution Discharges to the Great Lakes Basin

				Average BOD (T/D)		Average TSS (T/D)		Average Flow (1000m3/D)	
	Receiving Water	**Facility Name**	**City**	**1987**	**1992**	**1987**	**1992**	**1987**	**1992**
Lake Michigan, cont'd									
40	Paw Paw River	Silverleaf Paper	Watervliet	.39	.11	.36	.17	.90	1.78
41	Fox River	Wisconsin Tissue Mills	Menasha	.30	.52	.33	.53	10.90	21.52
42	Lacey Creek	Simplicity Pattern Co.	Niles	NA	.02	NA	.03	NA	.88
			TOTALS	**21.03**	**16.36**	**21.62**	**19.2**	**615.10**	**614.76**
	Lake Ontario								
43	Oswego River	Armstrong Cork Co.	Volney	.24	.23	.37	.22	8.50	8.27
44	Twelve Mile Creek	Beaver Wood Fibre Co.	Thorold	1.98	1.46	1.09	.62	15.90	14.00
45	Moose River	Burrows Paper Corp.	Lyonsdale	.13	.07	.17	.06	2.10	4.41
46	Twelve Mile Creek	Domtar Specialty Fine Papers	St. Catharines	.68	.88	.15	.30	9.30	9.35
47	Trent River	Domtar Packaging	Trenton	7.21	6.38	2.40	.64	3.40	4.09
48	Twelve Mile Creek	Thorold Specialty Papers	Thorold	2.25	2.47	.92	1.24	25.80	25.36
49	Black River	Georgia-Pacific Co.	Lyons Falls	1.64	1.15	2.21	2.55	15.90	14.04
50	Old Welland Canal	Kimberly-Clark of Canada	St. Catharines	.41	.21	.29	.08	9.90	11.09
51	Black River	Latex Fibre Ind.	Brownville	.08	.10	.10	.12	1.50	1.93
52	Beaver River	Latex Fibre Ind.	Croghan	.36	.10	.29	.10	21.90	10.05
53	Twelve Mile Creek	QUNO Corporation	Thorold	4.24	.84	4.75	1.84	109.10	57.29
54	Salmon River	Schoeller Technical	Richland	.31	.07	.08	.03	6.50	6.44
55	Black River	St. Regis Paper Co.	Deferiet	.23	.30	.54	1.05	43.50	49.37
56	Napanee River	Strathcona Paper Company	Napanee	.13	.12	.13	.16	2.90	
57	Trent River	Sonoco	Trenton	1.71	1.95	.92	.38	25.80	2.31
58	Whitney Creek	U.S. Gypsum Co.	Oakfield	.08	.09	.07	.10	15.40	17.31
			TOTALS	**21.68**	**17.05**	**14.48**	**9.76**	**317.40**	**235.31**
	Lake Superior								
59	Lake Superior	James River	Marathon	13.55	12.24	2.48	1.64	61.60	
60	Chequamegon Bay	James River	Ashland	.24	.24	.29	.17	4.90	5.17
61	Thunder Bay Harbour	Provincial Papers	Thunder Bay	3.40	3.91	.90	1.29	50.50	42.66
62	Thunder Bay	Abitibi-Price Ft. William	Thunder Bay	12.44	9.3	1.84	1.14	26.00	23.70
63	Thunder Bay	Abitibi-Price Thunder Bay	Thunder Bay	19.50	closed	1.40	closed	37.80	closed
64	Nipigon Bay	Domtar Packaging Ltd.	Red Rock	15.89	13.58	4.79	4.35	96.60	86.00
65	Kaministikwia River	Avenor	Thunder Bay	44.95	24.08	11.34	16.83	222.00	205.64
66	Lake Superior	Kimberly-Clark Corp.	Munising	.13	.10	.07	.04	20.00	20.53
67	Jackfish Bay	Kimberly-Clark of Canada	Terrace Bay	24.85	1.92	5.57	4.72	115.00	108.35
68	Ontonagon River	Stone Container	Ontonagon	3.89	.51	11.36	1.29	26.80	19.82
69	Lake Superior	Superior Fiber Products	Weyerhauser	2.21	.94	.11	.10	2.50	.48
			TOTALS	**141.05**	**66.82**	**40.15**	**31.57**	**663.70**	**512.35**
	St. Lawrence								
70	St. Lawrence River	Domtar Specialty Fine Papers	Cornwall	13.88	17.43	7.07	6.47	102.40	140.74
71	Oswegatchie River	James River Corp.	Gouverneur	.02	.07	.02	.04	.80	3.20
72	Oswegatchie River	Papyrus-Newton Falls	Newton Falls	.37	.16	.28	.20	25.50	21.83
73	Raquette River	Potsdam Paper Co.	Potsdam	.33	.44	.09	.09	5.30	4.51
74	Raquette River	Norfolk Paper Co.	Norfolk	.19	.168	.15	.08	22.70	10.85
			TOTALS	**14.79**	**18.268**	**7.61**	**6.88**	**156.70**	**181.13**

Source: Assembled by IJC Staff

1.3 ROW-CROP PESTICIDES AND RELATED AGRICULTURAL ISSUES

1.3.1 Background

The Great Lakes basin is among the most intensively cultivated areas in North America and, as such, receives significant applications of pesticides. In its 1983 report to the Commission, the **Great Lakes Water Quality Board** (WQB) examined the issue of controlling nonpoint source pollution, including that from pesticides, and concluded that one of the most appropriate management tools was reduced tillage practices (conservation tillage, including no-till).

In 1986-87, the Water Quality Board completed an initial assessment of urban and rural pesticide usage in the Great Lakes basin (WQB 1987). It determined that the highest agricultural applications were in counties adjacent to Lake Erie where corn and soybeans are the principal crops. In the same report, the Board indicated that non-agricultural applications of certain pesticides, particularly in or near urban areas, exceeded the per-acre agricultural applications. Since the completion of this earlier WQB work, much of the attention in regard to agricultural pesticide usage has further shifted from the historically used pesticides such as DDT to current use herbicides, particularly the triazines.

Row-crop pesticide applications were examined on the U.S. portion of the Great Lakes basin for 1991 and 1993. Pesticides applied to corn and soybeans on the U.S. side totalled more than 11 million kilograms of **active ingredient** (A.I.) for 1991 and close to 10 million kilograms of A.I. for 1993. Commission staff also assembled data on row-crop pesticide applications on a county-by-county basis with a particular emphasis on the Lake Erie basin. These data were then entered into a geographic information system. Figures 3, 4 and 5 show the 1993 pesticide usage in the Great Lakes basin for corn, soybeans and the summation of corn and soybeans, respectively. These data confirm that selected counties in the Lake Erie basin are among the highest in the Great Lakes basin in pesticide usage for these crops.

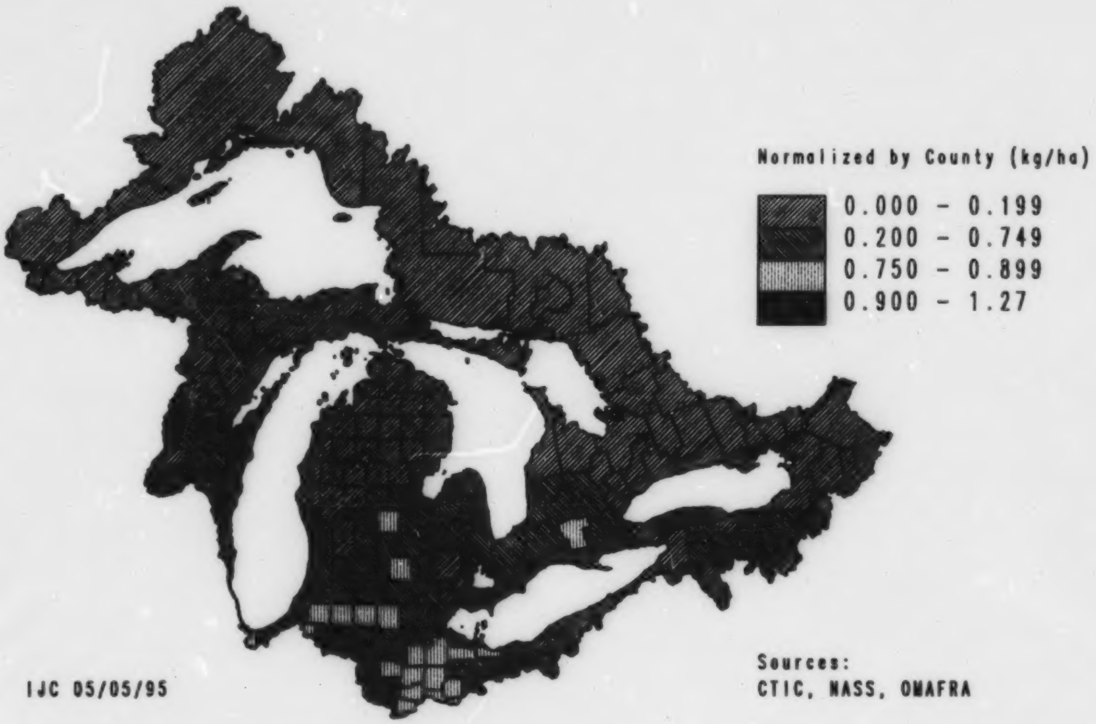
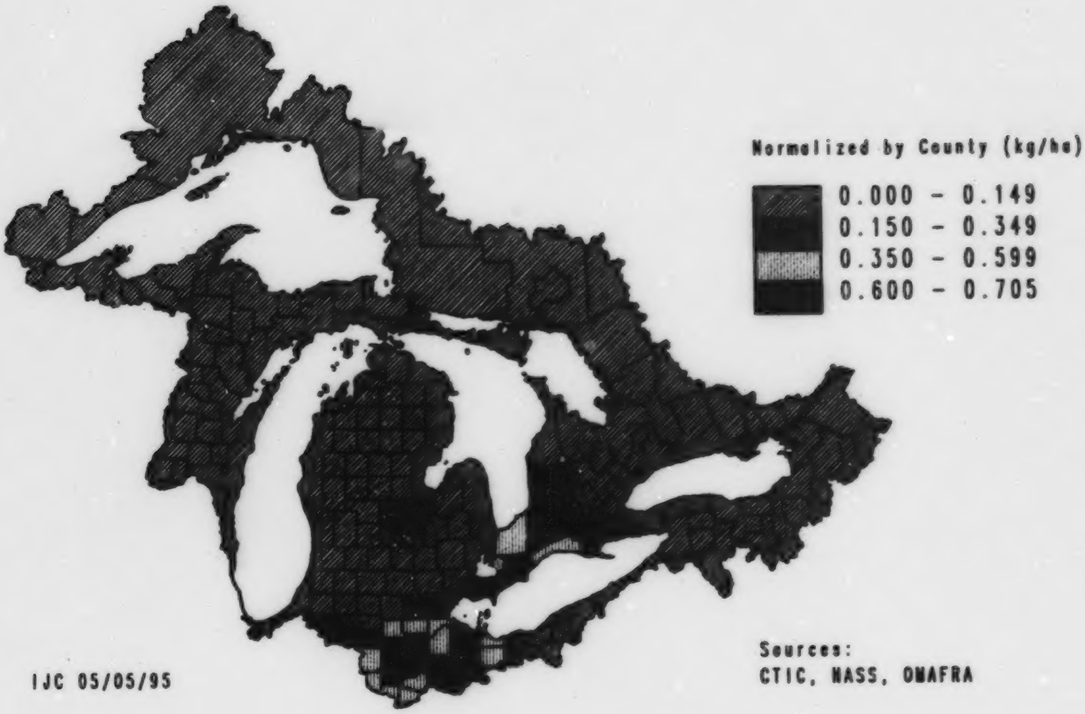


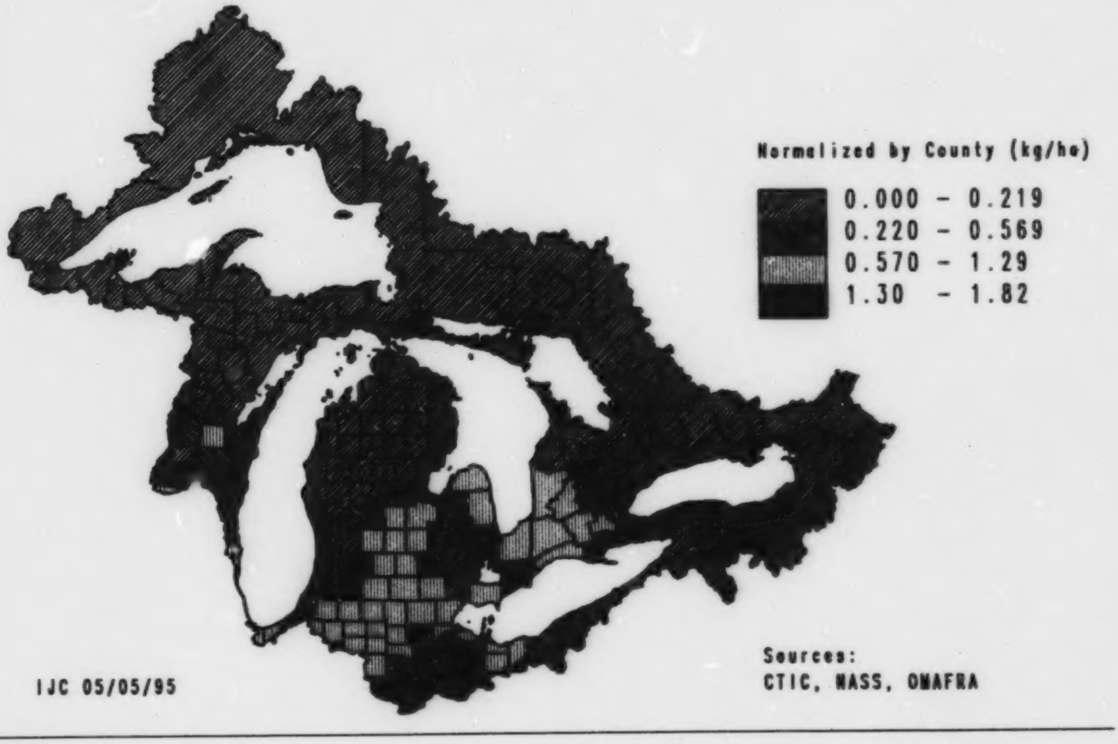
Figure 3.
1993 Pesticide Usage for Corn


Normalized by County (kg/ha)
0.000 - 0.149
0.150 - 0.349
0.350 - 0.599
0.600 - 0.705

IJC 05/05/95

Sources:
CTIC, NASS, OMAFRA

Figure 4.
1993 Pesticide Usage for Soybeans


Normalized by County (kg/ha)
0.000 - 0.219
0.220 - 0.569
0.570 - 1.29
1.30 - 1.82

IJC 05/05/95

Sources:
CTIC, NASS, OMAFRA

Figure 5.
1993 Pesticide Usage for Corn and Soybeans

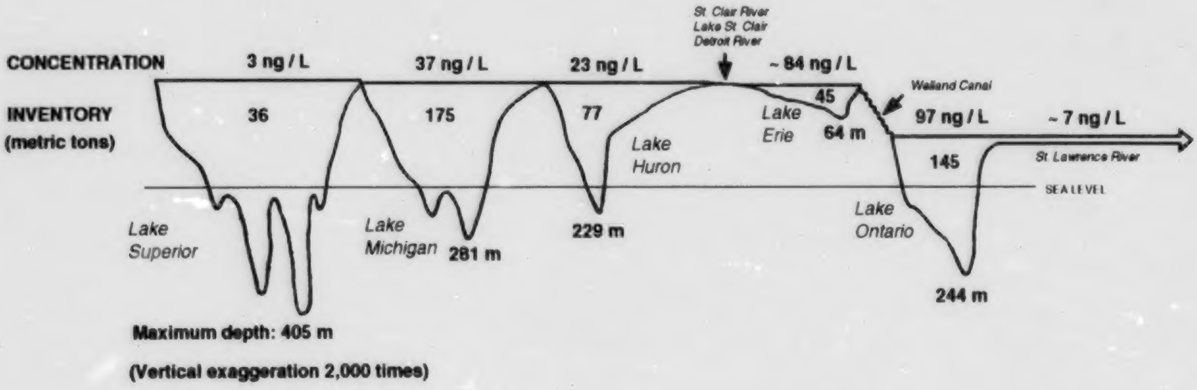
The applications of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) were of particular interest, due to its known occurrence in Lake Erie tributaries used as public drinking water supplies.

Until recently, little data were available on the occurrence of atrazine in open lake waters. A first estimate of total atrazine and the transformation product **desethylatrazine** (DEA) was 68 metric tons for the waters of Lake Erie in 1993; the concentration of atrazine in open lake waters for the same year was 75 ng/L and 93 ng/L for the western basin and eastern basin of Lake Erie, respectively (Schottler and Eisenreich, 1994). The concentrations of DEA in 1993 for the western basin and eastern basin were 47 and 67 ng/L, respectively. Schottler and Eisenreich (1994) concluded that "(A)trazine is well mixed both vertically and laterally in the lakes, indicating that the water column residence times must be long, with half-lives on the order of months to years."

In fact, their estimates of the half-life for atrazine ranged from five months in the western basin of Lake Erie to as long as 10 years for Lake Michigan. Accordingly, as defined by the Great Lakes Water Quality Agreement, atrazine is one of the few agricultural pesticides which could, on the basis of estimated half-life in the environment, be considered a persistent toxic substance.

Atrazine concentration levels have been examined elsewhere in the Great Lakes Basin Ecosystem. An estimate of atrazine concentration and inventory for each of the Great Lakes is displayed in Figure 6. An approximation of atrazine concentration for the St. Lawrence River is also displayed in Figure 6. Average annual concentrations in the St. Lawrence River were 10.4 and 3.4 ng/L in 1990 and 1991, respectively (Lemieux, Quémerais and Lum, 1995). The draft Lakewide Management Plan for Lake Michigan (U.S. EPA 1993) lists atrazine as an emerging pollutant, defined as "one which has the potential to impact the physical or biological integrity of Lake Michigan." Schottler and Eisenreich (1994) estimated the total inventory of atrazine and DEA for Lake Michigan waters to be 275 metric tons in 1993, and the concentration of atrazine and DEA in open lake waters for the same year were 37 and 24 ng/L, respectively. The draft LaMP recommends that such emerging pollutants be considered as priorities for data gathering and research activities. Despite a shorter half-life in Lake Erie, due to the greater application rates and relative lack of stream buffers in Lake Erie basin, atrazine should be considered a critical pollutant for the Lake Erie LaMP.

Atrazine applications throughout the basin for 1993 were 2,770,000 kilograms. This herbicide has been documented as an endocrine-disrupting chemical (Colborn, vom Saal and Soto, 1993) and, although precise use figures have not yet been determined for the Lake Erie basin for 1993, atrazine can be expected to have among the highest applications by weight of all agricultural pesticides. The endocrine disrupting potential of this herbicide is of most concern in the western basin of Lake Erie, due to the elevated levels of another known endocrine disruptor — polychlorinated biphenyls — also present in that area.



Modified from:
Schottler and Eisenreich 1994
Lemieux, Quémerais and Lum 1995

Figure 6.
Atrazine in the Great Lakes

1.3.2 Board Activities under the 1993-95 Lake Erie Priority

As part of their execution of the Lake Erie priority, the Water Quality Board sponsored two workshops on Pesticides and Related Issues in Toledo Ohio, on August 30, 1994 and on March 27 and 28, 1995. Farmers, representatives of government agricultural and environmental agencies, academics, and representatives of public interest groups and pesticide producers were in attendance. Drawing upon the earlier Commission focus on conservation tillage practices and pesticide applications, the workshops considered broad methodologies designed to affect significant reductions in pesticides in Lake Erie and the Maumee River.

Ontario's Food Systems 2002 initiative was among the programs reviewed. The Ministry target is a 50% reduction in pesticide applications by 2002. The program goals are: i) preserve and augment beneficial species; ii) consider the economic threshold for the use of alternatives to pesticide applications; iii) examine the preventive approach to pest control versus the corrective one, largely realized through pesticide application; iv) reduce impacts on the environment; and v) address health and social issues while arriving at sustainability. As a result of several factors, including the emerging pesticide resistance among key species, **Integrated Pest Management** (IPM) was advanced as a cornerstone of the program.

One definition of IPM, drawn from the June 1990 report on this subject by the Science Advisory Board, is "the optimization of pest control in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazard to humans, animals, plants and the environment" (Dover 1985).

The program has three pillars. The first is **education**, including training applicators through a mandatory certification program (a course for vendors is also offered). **Research**, largely supported through the Agricultural Research Institute of Ontario (95 projects), is another. Criteria for funding include consideration of nonchemical alternatives, examinations of efficiency of application technology, and a systems approach to pest control.

Finally, **field delivery** has been assigned to 15 management advisors responsible for fruits and vegetables, both field and greenhouse crops. Twenty-two commodities are covered under an IPM program, and a pest management hotline has been established. A major component is development of Environmental Farm Plans by individual growers, with a target of 5,000 completed plans by the end of 1994. Other responsibilities undertaken included pesticide collection, disposal and recycling, a Vegetation Management Advisory Program, Pest Diagnostic Advisory Clinic, and Turfgrass Nursery IPM Initiatives.

According to the most recent Ontario Pesticide Survey, since 1987 application of pesticide active ingredient has been reduced by 17%; a 40% reduction in applications to corn appears within reach and a fifty percent (50%) reduction to potato crops has been realized along with an 80% reduction in use on greenhouse floriculture.

Some identified ongoing concerns include: i) too narrow a focus, in that programs are still pesticide driven; ii) a lack of uniform standards/thresholds and methodology; iii) few pesticides are developed with IPM in mind; iv) a need to improve management of the introduction of new cultivars into a complex; v) the dominance of food appearance as a consideration; vi) a need for more education and delivery; and vii) erosion of the research effort due to a lack of long-term commitment. To 1992, the Ministry has carried 85% of the cost of these programs; they now fund only one-half of the program. Firm support for the balance had not yet been identified.

Representatives of the pesticide manufacturers reviewed their involvement in no-till demonstration tours; crop residue management conferences; preparing educational materials and encouraging conservation practices, including the development of buffer zones in fields adjacent to streams, rivers and lakes, and development of a "Code of Practice" for pesticide usage. Application education was being addressed through the development of "Codes of Application." "Well assist" programs for the identification and rehabilitation of contaminated farm wells are also being supported, as well as herbicide consultations, genetic engineering efforts and the application of biotechnology to develop better crops.

Further evidence of recent reductions in herbicide loading to the environment, largely as a result of more effective application and results, was offered at the workshop. Although treated acreage remained comparable from 1985 to 1990 in Illinois, the amount of pesticide **Active Ingredient** (AI) applied had decreased. Current instructions for the common herbicide "Roundup" call for half the application previously recommended.

The extent of conservation tillage for stream and river sediment control in a substantial portion of the Lake Erie basin also was reviewed. Sediments were about 50% of all primary river pollutant loadings. The level of conservation tillage applications is estimated at one-third of all cultivated acreage. Under the 1985 U.S. Farm Bill, soil erosion has been reduced by that same fraction.

While it has been suggested that no-till farming uses more pesticides, the impact on the larger environment may not be detrimental in these cases, given improved soil containment. After initial use following introduction of no-till practices, pesticide amounts are typically reduced. Thus, corn yields have levelled or decreased slightly in no-till applications and chemical usage has dropped. IPM was being used and most pesticide applications were now to surface postemergent plants at lower application levels.

Emerging technologies such as biogenetics, global positioning and soil doctoring, which determine the precise field location and fertilizer requirement, were noted as positive developments.

Academic researchers examined some of the hormonal imbalances, changes in cell masses, reproduction and growth, and immune and nervous system function in certain species of mammals in response to stressors, including pesticides. Aldicarb, atrazine and nitrate mixes were tested at levels that were present in groundwaters in part of the basin, seeking hormone, endocrine and immune system disruption. "Aggression" behavioral factors were also considered and two- and three-factor interactions showed an impact associated with these chemicals.

A 1986 study on the pesticide 2,4-D demonstrated that effects emerged after only one year. Animals in the wild are subjected to many more stresses; it was suggested that experiments should be performed outdoors, as higher toxicity impacts could be evident under such circumstances. Testing needed to be revised with multiple exposures, more endpoints in addition to cancer, and the use of chemical mixtures and more stressors (disease, nutrition and climate).

Some reduction in growth hormone in the species examined was noted. Impacts on the immune system remained a concern, which should be addressed through a mixture testing approach at groundwater concentrations. Further, while no-till was effective in controlling runoff to surface water bodies, the degree of migration to and impacts on groundwater remained unclear.

A representative of the **World Wildlife Fund** (WWF) outlined that organization's belief that a major initiative to reduce pesticide risk in the Great Lakes basin was appropriate, based on both human health and economic considerations. Endocrine system disruption or modulation and immune system compromise in selected species were particular concerns.

The WWF pesticide application inventory under development considered pesticide sources such as food storage, golf courses and lawns, in addition to traditional agricultural applications. The form and amount of pesticide movement off the lands are well quantified. Categories of pesticides, some of which are persistent and bioaccumulative, were reviewed. Further emphasis was given to those that disrupted the endocrine system, put birds at risk and had other possible undesirable outcomes.

Other identified concerns included: i) the cancer risk in farmers and workers; ii) endangered or imperiled species; and iii) the effect of low doses or single exposures to pesticides on reproduction of various species.

Major issues identified specific to the Maumee basin of Lake Erie included: the desire to reduce pesticide use; questions dealing with risk management; need for an inventory of the extent of no-till and an assessment of its effects through cost-benefit analysis; the registration of biological agents; the environmental objectives of wildlife/animal protection; the need for further local farmer-to-farmer interaction; exploring the basis for determining and achieving a "healthy ecosystem"; accountability for voluntary programs; further assistance in technology transfer; the need to continually account for economics.

There appeared to be a general consensus that the key elements of any future approach to reducing pesticide use and associated loss to the environment would include use of no-till cultivation, integrated pest management, and whole farm planning. There was also a suggestion that water-soluble herbicides associated with corn and soybeans should be further examined; development of a partnership among growers, chemical companies, distributors and consumers, as well as the academic community, was also proposed.

The need for further research to establish baseline reporting systems was evident. Profitable alternatives to pesticides involving chemical and biological IPM, the use of Geopositioning Systems for more accurate pesticide application, as well as variable application rate technology were all discussed.

Education and technology transfer should be encouraged through public access to information, farmer networks for education and the use of professional researchers in an on-farm setting. The agricultural retailer could perform a useful role in IPM education and tracking programs. The coordinated collection of data using a common methodology, and a move to whole farm planning, were also advocated.

Policy changes toward mixed commodity market programs (diversify crops toward hay, for example) and a patent period extension for types of pesticides/herbicides that are more benign were suggested. Development of a market for food grown using some of the available alternatives could increase application of innovative equipment, production and services.

It was suggested that any established goals for pesticide reductions should be realistic (perhaps based on the drinking water standards); economic incentives and technical support should be included in the promotion of such reductions.

1.3.3 Workshop Conclusions/ Recommendations

Further research is needed on pesticide application rates and, in some cases, possible subtle endocrine effects. Appropriate reduction targets to safeguard human, wildlife and ecosystem health should be considered for incorporation in appropriate RAPs and LaMPs, particularly those associated with Lake Erie.

Database development and analysis for no-till and pesticide applications should be pursued on a binational basis and the application of geopositioning, remote sensing, biotechnology and other emerging capabilities for further delineation of these issues should be explored.

Effective communication on a farmer-to-farmer basis, including the government agencies, the farm suppliers and manufacturers, and the academic community, should be supported and encouraged.

1.4 GROUNDWATER IN THE LAKE ERIE BASIN

Annex 16 of the Great Lakes Water Quality Agreement, as amended by Protocol and signed November 18, 1987, states that the Canadian and American governments shall identify, map and control sources of groundwater contamination affecting the Great Lakes. The Water Quality Board completed a literature review to evaluate scientific knowledge concerning the role of groundwater in shaping Lake Erie water quality. Tile drainage of cultivated areas was considered within the context of this review, as tile drains are considered to be conduits for groundwater to surface water bodies.

The qualitative and quantitative contribution of groundwater to Lake Erie is poorly defined in the scientific literature. Current data gaps include mapping hydraulic potential in Lake Erie bottom sediment, estimating nearshore and offshore groundwater flux, determining the extent and significance of subsurface geologic heterogeneities (including faults) in the Lake Erie basin, and quantifying the extent of chemical loading via groundwater.

The topography of Lake Erie divides into three distinct regions. West of Pelee Island is a shallow basin that averages 7.3 meters (24 feet) in depth. A broad, flat-bottomed central region, averaging 18.3 meters (60 feet) in depth, extends from Pelee Island to a sand and gravel ridge that transects the lake from Long Point, Ontario to Erie County, Pennsylvania. The eastern basin, extending from Long Point to the Niagara River, is the deepest portion of the lake, averaging 24.5 meters (80 feet). Composition of bottom material is highly variable, ranging from silt and organic detritus to sand, gravel and exposed bedrock. A layer of compacted glacial till is also present and appears to be spatially variable.

The bedrock geology of the Lake Erie basin is dominated by sedimentary rock of Devonian and Silurian age. These limestones, dolomites and shales typically exhibit extensive fracturing. An example of a major regional structure is the Bowling Green Fault which runs north-south through the carbonate bedrock of northern Ohio.

Overlying the bedrock of the Lake Erie basin are till, glaciofluvial and lacustrine sediments, beach ridge deposits, and/or glacial land forms such as moraines, drumlins and kames. The till and lacustrine deposits are clay rich, exhibiting variable hydraulic conductivities, or water conductance properties, which change with depth and the extent of fracture development. Conversely, fluvial sediment, beach ridges, and certain moraines are composed of highly permeable sands and gravels, which introduce considerable variability to the Lake Erie hydraulic conductivity profile.

A variety of methods have been employed to obtain hydraulic potential readings in bottom sediments of the Great Lakes. One particularly promising approach involves obtaining electrical conductivity measurements of bottom sediment, which can then be related to the ability of water to pass through these zones. Aside from being relatively cost effective, this method may prove to be more accurate than conventional coring practices.

Variability in soil and sediment hydraulic potential directly impacts groundwater flow patterns and velocity in the Lake Erie basin. Increased tributary base flow, due to highly porous sediments, is evident in the Big Creek, Ontario drainage basin where approximately 43 percent of mean annual flow and 95 percent of summer flow are attributable to groundwater discharge.

Excluding the Detroit River, direct tributary flow to Lake Erie is approximately 2.2×10^{10} m^3 (7.8×10^{11} ft^3) per year. Between 20 and 60 percent of this flow is contributed by groundwater base-flow. Direct groundwater flow to the St. Clair River, Lake St. Clair and Detroit River has been estimated to approximate 7.2×10^7 m^3 (2.5×10^9 ft^3) per year. Estimating direct groundwater flux to Lake Erie was not possible due to a lack of adequate and sufficient data. An estimate of 3.6×10^6 m^3 (1.3×10^8 ft^3) per year was obtained from the literature, although the model used to obtain this figure solely considered deep groundwater flow through fractured bedrock (not flow through nearshore sediment) and did not fully account for subsurface heterogeneities. Research performed in Lake Michigan, however, indicates that groundwater flow through near-shore sediment significantly exceeds groundwater flow through offshore sediment.

At a local level, perched aquifers form within sand and gravel deposits that are underlain by less permeable glacial till, such as those found in Perry, Ohio. These shallow aquifers are highly susceptible to anthropogenic sources of contamination, such as nitrate and chloride pollution.

Naturally occurring groundwater pollutants in the Lake Erie basin include metals, hydrocarbons, (BTEX or Benzene, Toluene, Ethyl Benzene and Xylenes from petroleum seeps), and chloride. These natural sources are further augmented by inputs from human activity, which together comprise the total chemical loading of these substances to Lake Erie. In the Maumee River basin, groundwater contributes 75 to 95 percent of the background levels of various heavy metals, including chromium, copper, nickel, lead and zinc.

Agricultural pollutants, particularly herbicides and nitrate, are common groundwater pollutants throughout agricultural regions of the Lake Erie basin. Studies concerning mobility and fate of the herbicide atrazine indicate that between 1.0 and 1.5 percent of the total quantity applied to an agricultural site may be discharged to surface waters via tile drainage. A study conducted in Southern Ontario indicated that approximately 50 kg of nitrate per hectare per year (45 lbs N/acre/year) leached to groundwater in a study conducted in southern Ontario, with approximately 10-20 kg N/ha/year (9-18 lbs N/acre/year) discharging to the local stream watershed via groundwater flow. Base flow has been estimated to contribute 25-50 percent of total stream flow nitrate loading in an unglaciated portion of east-central Ohio.

Deep well injection of industrial waste continues to be practiced in Lake Erie basin states including Ohio and Michigan.

1.4.1 Conclusions and Recommendations

Scientific knowledge concerning the role of groundwater in shaping Lake Erie water is incomplete and unintegrated. However, apparently groundwater plays a significant and potentially more important role than surface runoff in directing drainage to Lake Erie and in transporting nitrogen, pesticides, heavy metals and other contaminants to the lake. Estimates of groundwater flow to Lake Erie tributaries range from 20 to 60 percent of total flow. In topographically flat, poorly drained regions, such as the extensive clay plains of southwestern Ontario and western Ohio, baseflow, combined with agricultural tile drain effluent, probably accounts for a major part of tributary flow. Research is required to develop base-flow estimates for individual watersheds within the Lake Erie basin, as well as to assess the implications of anthropogenic groundwater withdrawals and surface water impoundment/diversion practices on base-flow maintenance.

Considerable hydraulic variation exists within bedrock and sediment throughout the Lake Erie basin. The fractured limestone/dolomite bedrock common throughout much of the basin can transmit large quantities of water. Buried valleys, solution channels and other macropores further add to the volume of water discharged. Natural faults and thousands of abandoned oil and gas and water wells add considerable complexity to subsurface flow in the Lake Erie basin. Septic systems at permanent and seasonal dwellings which line Lake Erie and its tributaries are often poorly maintained and are a major source of ground and surface water contamination (Figure 7). Recent evidence suggests that the clay till sediments common throughout the western portion of the Lake Erie basin are more hydraulically conductive than previously believed, due to extensive fracturing.

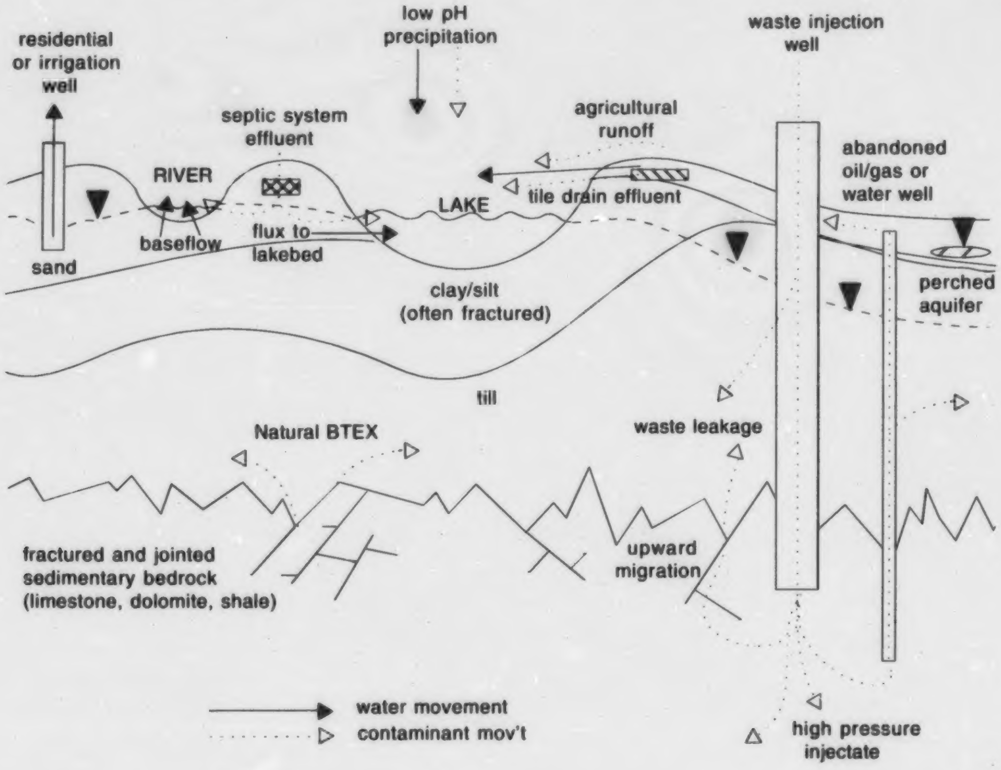

low pH
precipitation
residential
or irrigation
well
waste injection
well
septic system
effluent
agricultural
runoff
abandoned
oil/gas or
water well
RIVER
LAKE
tile drain effluent
baseflow
flux to
lakebed
sand
perched
aquifer
clay/silt
(often fractured)
till
Natural BTEX
waste leakage
fractured and jointed
sedimentary bedrock
(limestone, dolomite, shale)
upward
migration
water movement
contaminant mov't
high pressure
injectate

Figure 7.
Schematic Drawing of Some Influences on Groundwater Quality in the Lake Erie Basin

To date, little progress has been made towards fulfilling Annex 16 of the Great Lakes Water Quality Agreement. Due to a lack of applicable research, the role of groundwater in shaping the water quality of Lake Erie cannot be adequately assessed. Numerous research opportunities exist that would resolve data deficiencies. These include:

- The compilation of existing Lake Erie basin geological, hydrological and hydrogeological research. Such information is fragmented amongst academic institutions and government agencies within the basin.
- Field assessments of Lake Erie bottom sediment hydraulic potential. Identifying subsurface heterogeneities which provide for rapid groundwater flux is a subject of particular urgency. Conducting geoelectrical field survey(s) may prove to be a reliable, cost-effective method to obtain this information.
- Mapping the occurrence of fault systems within the Lake Erie basin and their associated impact on groundwater flow and contaminant transport, especially in and around Areas of Concern.
- Characterizing the chemical composition of groundwater discharging to Lake Erie and to Lake Erie tributaries.

It is important to note that remediation of contaminated aquifers has proven to be an extremely difficult task, judging from experience gained from "Superfund" sites in the U.S. According to Annex 16 of the Great Lakes Water Quality Agreement, the Parties have agreed to "control the sources of contamination and the contaminated groundwater itself" within the Great Lakes basin. The implementation of groundwater protection schemes, such as well-head protection programs, are a matter of urgency throughout the Great Lakes basin.

1.4.2 Water Quality Board Recommendation

The Water Quality Board recommends that:

The Commission should promote the preventive approach in protection of the groundwater resource and encourage the Parties to proactively implement Annex 16 of the Agreement.

1.5 FUTURE DIRECTIONS

In its comments to the Commission regarding the 1995-97 priorities and beyond, the Board has suggested that a focus on the impact of persistent toxic substances on human and ecosystem health in conjunction with the Science Advisory Board. Further, the Board has advocated a review of the Critical Eleven list of persistent toxic substances established by the Board in the mid-1980s, and a further examination of the various pathways for such substances to the lakes, in continental and global contexts.

In support of the continuing evolution of **Remedial Action Plans** (RAPs) and **Lakewide Management Plans** (LaMPs), a review of the application of current, particularly *in situ*, technology for the remediation of sediments contaminated by persistent toxic substances appears appropriate.

The Board has also expressed an interest in a coordinated review of the status and adequacy of programs to control the access of exotic species, such as the zebra mussel, to the basin.

While the Board cannot clearly define its own possible role, the impact of revised program support and emerging powerful information technologies, such as the Internet, suggest that a review of the state of binational information collection, management and dissemination activities would be appropriate. The contribution of these efforts to effective public education could also be considered.

With regard to the Board's activities under the 1993/95 biennial cycle, the Board felt a further review of pollution prevention efforts in the Basin would be appropriate. It also recognized the Parties' effort in hosting SOLEC (the State of the Lakes Ecosystem Conference) at Dearborn, Michigan in October 1994. A proceedings from this conference was to follow as of mid-1995; it is the Board's understanding that this document is to be formally transmitted to the Commission as part of the Parties review of progress under the Great Lakes Water Quality Agreement. The Board stands ready to assist the Commission in any appropriate way with the review and consideration of this document and the related process.

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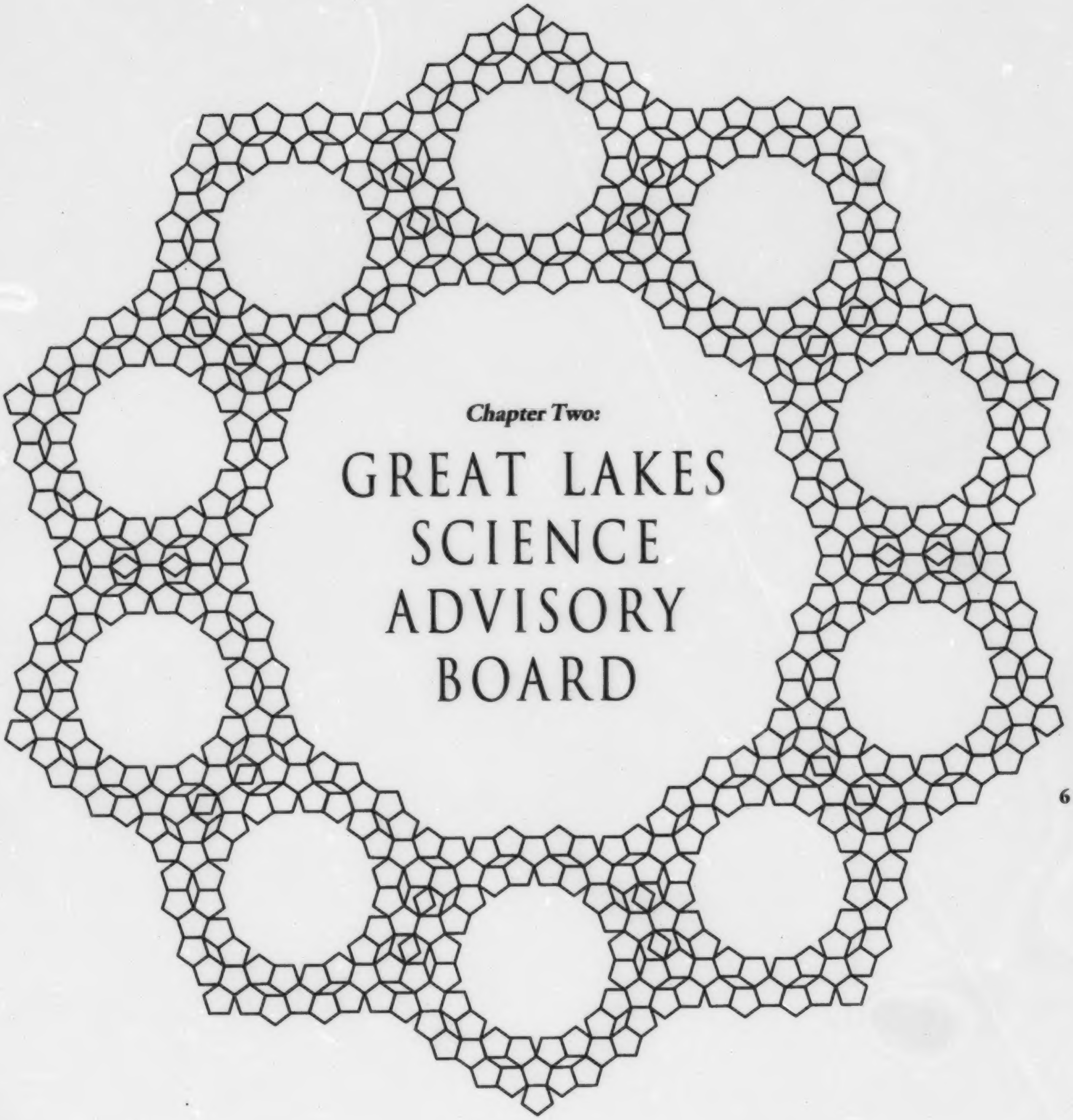

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GREAT LAKES SCIENCE ADVISORY BOARD

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2.0 SCIENCE ADVISORY BOARD ACTIVITIES

Introduction

The Great Lakes Water Quality Agreement provides the Terms of Reference for the **Science Advisory Board** (SAB) as a joint institution to be "... the scientific advisor to the Commission and the Water Quality Board." Through an integrative approach, including the natural, physical and social sciences, the principle role of the Board relates to three areas:

- assessment and advice on Great Lakes Basin Ecosystem health, including the scientific underpinning of public policy
- review and evaluation of science policy and programs related to the Parties' implementation of the Agreement
- identification and evaluation of emerging issues and future priorities.

To meet these responsibilities, the Board comprises 18 members appointed by the Commission on the basis of their experience and expertise, to provide independent scientific advice under the Agreement. Science Advisory Board members are recruited from industry, academia, government and nongovernment organizations, and the Board is multidisciplinary in its expertise.

To substantively address matters referred to it by the Commission under the 1993-95 Priorities, the Board continued to employ three workgroups composed of SAB members and non-Board members with pertinent expertise. The Board workgroups focus on Ecosystem Health, Parties Implementation, and Emerging Issues. Generally, each workgroup met quarterly and reported to the Board at its regular meetings. During the 1993-95 Biennium, the IJC priorities assigned to the Board and Board initiatives regarding emerging issues and technology assessment were delegated to the workgroups as follows:

- Workgroup on Ecosystem Health:
  Toxicological Mechanisms; Weight of Evidence; and Measuring Ecosystem Health
- Workgroup on Parties Implementation:
  Parties Toxics Reduction Programs; and Followup on the Virtual Elimination Task Force
- Workgroup on Emerging Issues:
  Climate Change; Emerging Issues; and the technology component of the Water Quality Board's Workshop on Pollution Prevention

Workgroup reports, conclusions and recommendations are reviewed, compiled and approved by the Board for submission to the Commission in its Biennial Report.

In addition to non-Board members serving on the workgroups, the SAB also benefitted from the involvement of Water Quality Board and Council of Great Lakes Research Managers members serving on the workgroups in a support and/or liaison role. This involvement provided consultation and coordination on advisory activities under the priorities.

2.1 SUMMARY OF SCIENCE ADVISORY BOARD RECOMMENDATIONS

2.2 Human Health in Ecosystem Health: Issues of Meaning and Measurement

The Science Advisory Board recommends that:

- the Commission, in its priority activities and its advice to the Parties, support further research to determine ambient levels of exposure to toxic chemicals in the Great Lakes basin and incorporate the following general principles for further development of environmental burden of illness indicators:
    - continued monitoring of toxins in media, including trihalomethanes, nitrates, microbial contaminants in drinking water, PM-10, ozone and sulphates in air, and toxic bioaccumulative chemicals in general
    - systematic synthesis of water sampling results for microbial contaminants that result in beach closings. Consider complementing these with information on symptoms among beach users
    - inclusion of relevant ambient exposure factors (e.g. time outdoors, based on activity record) and consumption factors (e.g. freshwater fish and wildlife) in population-based health surveys. General population-based measures of body fluid levels of key contaminants (e.g. PCBs or DDE for the organochlorines in serum and breast milk, mercury and lead in whole blood for the metals) could be linked with these and other relevant social factors
    - surveillance of established environmental health outcomes, such as asthma, such that these conditions may be considered as sentinels for pollution effects
    - recognition that some human illness indicators are poorly suited to provide useful information on the impact of environmental matters on human health, e.g. most morbidity and mortality data that is routinely collected, including cancer rates
    - development of longitudinal designs around exposures and conditions of interest to enable stronger inferences concerning relationship between exposure and health outcomes.
- the Commission support actions that would lower human exposure to persistent toxic substances such as PCBs and lower concentrations of these substances in human tissues.
- the Commission support the development of indicators and scales that measure the environmental component of illness and wellbeing and indices of environmental stress and environmental condition.
- the Commission continue to monitor state of the environment and sustainable development reporting in order to inform, in its recommendations to the Parties, regarding Great Lakes basin indicators. As these reports often take a broad-based approach to indicator selection, this monitoring is necessary to help ensure the integration of human exposure considerations into assessments of contamination in relevant fish and wildlife species.

2.3 Weight of Evidence Approaches to Decisionmaking in the Face of Uncertainty

The Science Advisory Board recommends that:

- scientific risk characterization formally include disclosure of: (1) choices embedded in the design of supporting research; (2) modifiers of risk factors used; and (3) all relevant uncertainties.
- risk characterizations prepared for environmental decisionmaking explicitly examine the potential indirect consequences resulting from the characteristics of the hazard, pathways and host response as outlined in Appendix I of this section.
- decisionmakers seek out or recommend relevant valuation assessments, legal and regulatory analysis, socio-economic assessments, equity analysis, ethical analysis and cumulative impact assessments as necessary inputs into risk management decisions.
- Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties and consequences involved.
- the level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated.
- the risk of non-action be included in deliberations on risk management.
- Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of

progress toward the desired goal, or conversely as an indicator of a wrong decision.

- Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers.

- further development of an ethical basis for ordering and prioritizing goals of human health and/or environmental integrity, when there is a potential conflict between those goals, be undertaken.

2.4 Toxicological Mechanisms: Environmental Exposure to Chemicals Acting as Endocrine Modifiers

The Science Advisory Board recommends that:

- cooperative efforts occur between the governments, academia, the general public and industry to focus research:

  1. to identify which, if any, environmental exposures to chemicals are or have the potential to be endocrine modulators in humans. For those chemicals identified, what are the exposure and dose-response relationships that define the potential for adverse effects?

  2. to identify what effects and disease state in humans may be linked to endocrine modulation as a result of exposure to chemicals in the environment, and at what stage of development is the human most susceptible to these effects

  3. to identify the mechanisms of action of environmental exposures to chemicals relative to endocrine modulation, and how such knowledge can be factored into the risk assessment process

  4. to determine if structure/activity relationships can be developed to accurately predict which environmental exposures to chemicals have the potential to modulate the endocrine system

  5. to determine if sensitive biomarkers of endocrine modulation can be developed and validated for use in animals and humans exposed to chemicals in the environment

  6. to determine in animals if environmental exposures to chemicals that are endocrine modulators can be differentiated from other environmental stressors, such as loss of habitat, malnutrition, or changes in ecosystem dynamics that can similarly exert effects on the endocrine system

  7. to determine in humans if environmental exposures to chemicals that are endocrine modulators, can be differentiated from endocrine effects that are caused by endogenous, dietary or other lifestyle stressor factors (loss of jobs, etc.). How can their interactions be studied?

  8. to identify chemically-exposed cohorts that can be used to study the potential for environmental exposure to chemicals to alter endocrine function or endocrine responsive organ function

  9. to identify if technologies can be devised to control the release of endocrine modulators. Can more effective technologies be developed?

2.5 Federal and Provincial/State Toxic Reduction Programs and Related Activities in the Great Lakes Basin: A Preliminary Evaluation

The Science Advisory Board recommends that:

- the Commission consider toxics reduction programs as a priority for further action within the next biennial cycle. To further this priority item, the Commission should establish a special task force of the Science Advisory Board, in cooperation with the Water Quality Board and the Council of Great Lakes Research Managers, with a mandate to:

  (a) develop standardized binational mechanisms and criteria to assess toxic chemical management laws, programs and data collection activities

  (b) provide advice to the Commission on the design and implementation of such activities in order to assess toxics loadings to the Great Lakes basin.

- the Commission reiterate and re-emphasize to the Parties the recommendation from the Commission's *Seventh Biennial Report on Great Lakes Water Quality*, which stated:

  - Governments adopt a specific, coordinated binational strategy within two years with a common set of objectives and procedure for action to stop the input of persistent toxic substances into the Great Lakes environment, using the framework developed by the Virtual Elimination Task Force.

2.6 Progress Toward Virtual Elimination of Persistent Toxic Substances

The Science Advisory Board recommends that:

- the Commission consider transition planning as a priority for further study and research within the next biennial cycle. Components of this research should include:

  - a study researching a number of case histories of where there were specific efforts to facilitate the transition of an industrial sector owing to some change in circumstance (such as the downsizing of the military establishment or the phaseout of certain substances such as CFCs) to determine the lessons learned from those experiences

- an investigation to identify the major contributors of dioxin to the Great Lakes

- the development of a transition plan, with the participation of the important stakeholders, for the virtual elimination of dioxin inputs from one of the major contributors. The development of the plan design would serve as a forum for a discussion on both the general framework and the key components of a transition plan. The terms of reference of the study would include:

1. the definition of transition planning

2. important principles that would be included in plan design (such as who should participate in the fashioning of a plan, when it is necessary, among many others)

3. identification and feasibility of transition mechanisms (such as a transition fund) and the potential and obstacles for them to work in practice

4. the need to establish, if at all, an institutional framework for the development, implementation and monitoring of the transition process, whether at a local, regional, national or international level.

- the Commission sponsor one or more roundtables to engage the dialogue of stakeholders in the topic, and to further elaborate on how the term should be interpreted and applied.

- the Commission actively seek avenues to participate in international dialogue both within North America and beyond, on transition planning.

- the Commission reiterate recommendation 20 in its *Seventh Biennial Report* to the government in parti-cular, which stated that governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of initiatives designed to promote virtual elimination.

Further to this recommendation, that the Commission recommend to the governments within the Great Lakes basin that:

- transition planning components, when deemed necessary in the sense that there is a risk of significant worker or community dislocation, be included into the specific commitments to those substances that are already candidates for phaseout, such as those identified under the Canada-Ontario Agreement, and the Lake Superior Binational Program

- governments report back to the Commission biennially on progress made in furthering these transition mechanisms.

2.7 Impacts of Climate Change on the Great Lakes: Progress Towards a Binational Strategy

The Science Advisory Board recommends that:

- the Parties be encouraged to support the completion of the binational implementation plan through to 2001 according to the scheduled timeline as indicated in Table 6.

- a quinquennial symposium on climate change in the Great Lakes basin be sponsored by the Parties and be sustained following the event planned for 1996, as an important scientific forum for discussion and to measure progress towards climate change assessment and adaptation.

- the recommendation from the 1993 Science Advisory Board report, that the Parties make a long-term commitment to climate change research under Annex 17 of the Great Lakes Water Quality Agreement, and report progress in a holistic and systematic fashion within the context of a State of the Great Lakes Basin Ecosystem report, receive further consideration and emphasis in the Commission recommendations to the Parties.

2.8 Identification and Assessment of Emerging Issues

The Science Advisory Board recommends that:

- the issues identified as potentially important for the Commission be considered as priorities for serious deliberations during the next biennium. They are complex issues, especially the issue of sustainability that reappeared in each survey, that would require Commission resources to address in terms of implications for progress under the Great Lakes Water Quality Agreement. The issues assessed as most salient include:
  1. sustainable development
  2. stability of water levels
  3. uv-B effects on biota
  4. various implications of **North American Free Trade Agreement** (NAFTA)
  5. lifestyle choices as a factor in ecosystem integrity
  6. incidence of endometriosis in women who eat fish from the Great Lakes

2.2 HUMAN HEALTH IN ECOSYSTEM HEALTH: ISSUES OF MEANING AND MEASUREMENT

2.2.1 Introduction

The original task undertaken by the Subgroup on Measuring Ecosystem Health under the priorities for the 1993-1995 biennium was to prepare a discussion paper on methods for the diagnosis, prognosis, treatment and rehabilitation of ecosystems under stress. Most members attended the First International Symposium on Ecosystem Health and Medicine in Ottawa, on June 19-23, 1994. This symposium addressed the issues associated with this priority task in great detail. Based on the input from this symposium and discussion in the Subgroup, the scope of this task was focussed on clearly addressing the impact of ecosystems on human health and the role of human values in defining the "health" of an ecosystem. A contract was let with the Chair of Environmental Health, McMaster University to produce a monograph on this topic. This research chair within the Eco-Research Program under Environment Canada's Green Plan addresses environmental issues in an interdisciplinary way and includes exploration into the concept of ecosystem health among its research goals. The chairholder, John Eyles, a world renowned social geographer and his research associate, Donald Cole, an environmental epidemiologist, had the precise balance of skills to address the task. Their monograph, *Human Health in Ecosystem Health: Issues of Meaning and Measurement* has now been produced.

This section of the **Science Advisory Board** (SAB) Report draws heavily on the material contained in the monograph with the permission of the authors, as it was produced in parallel to the writing of the monograph. It is, however, not simply a condensation of the monograph. It represents the opinions of the Workgroup on Ecosystem Health of the SAB as accepted by the Board, and not necessarily in all aspects the opinions of Drs. Eyles and Cole.

The monograph discusses ecosystem health in relation to human environmental wellbeing in its broadest sense as an essential context for human health. It argues that a systematic review of quality of life indicators from a range of literature should be undertaken to develop appropriate health and wellbeing measures for Great Lakes basin populations that go beyond simple measures of environmental burden of illness. This section, because of its more limited scope, addresses human health primarily as defined as an absence of disease, i.e. to highlight for the SAB what is known about human disease that flows from exposure to agents within ecosystems, rather than being determined by human genetics, lifestyle behaviours, nutrition or social determinants such as class, poverty, education and self-esteem. The discussion of this environmental burden of illness and appropriate indicators for its measurement in the Great Lakes basin first requires a discussion of the concepts of ecosystem health and human health.

Ecosystem

The concept of ecosystem is rooted in the broader concept of ecology. Ecology refers to the branch of biology that deals with the interrelationships between organisms and their environment. Our experience of the natural world is highly conditioned by our experience of ourselves as body and other creatures as detected by our sense of vision as discreet organisms. Ecology attempts to see the whole and to understand the interconnections of things. The term ecosystem has been used in the science of ecology with many definitions but in three general senses.

Ecosystem can refer to an identifiable natural region; in this sense it is something real, an entity in itself rather than a human mental construct by which reality is understood. It is the geographical landscape and everything in it. As such it is something that we as humans can value and relate to, but it is not a model or analytical framework for scientific inquiry. The Great Lakes Basin Ecosystem, for example, has a geographic dimension that humans can understand and perceive. Ecosystem as a scientific model within which measurements can be made has been approached from two perspectives. One approach is the population-community approach, which focuses on the growth of populations, the structure and composition of communities of organisms and the interactions among individual organisms (O'Neill et al. 1986). This approach views ecosystems as networks of interacting living populations, so in effect the biota are the ecosystem while the non-living components are understood to be external influences or the backdrop in which biotic interactions occur. The other approach is the process-functional approach that emphasizes biophysical models of energy flows and nutrient cycling (e.g. Kay 1991).

Ecosystem can also be viewed as a completely abstracted management tool. Allen and Hoekstra (1992) argue that the observer uses a filter to engage the world. It involves not only definitions and identifying critical changes, but also the nature of measurement and the data collection process. The ecosystem is the system our measuring tools and information gathering techniques allow us to see. Put slightly differently, the human impact on ecosystems is dependent in part on *how* as well as *what* we observe (Bandurski 1994).

Human Health

What is human health? This term has been used in positive and negative senses. The biomedical approach to health has been the absence of disease, in which disease is an abnormality in a part of the body (or by extension of the mind). This biomedical approach is the basis for most toxicological and epidemiological research on human health consequences, on exposure and outcomes. This concept of absence of disease can be used analogously with ecosystems as an absence of distress.

A second "negative" definition of health is the absence of illness. Illness may or may not be associated with disease. The distinction often used is that disease is diagnosed by a physician or other health care professional, while illness is experienced. If an individual does not experience anxiety, pain or distress even if they are diseased, s/he is healthy. Conversely, even in the absence of disease, if an individual does experience anxiety, pain or distress, that individual is unhealthy. In the environmental arena the perception of risk related to exposure to chemicals or other agents in the environment is often a cause of anxiety and distress and thus a source of ill health. It is important to note, however, that the risk that is feared is that a toxic agent has already or will cause a disease. Our concept of what is good and bad in our modern science-oriented society is highly conditioned by the biomedical model. This definition of health does not easily translate to ecosystems. Our common anthropocentric belief is that humans are the most conscious organisms in the ecosystem and therefore we are more subject to pain and anxiety than other organisms.

There are four positive definitions of human health. First, health may be seen as that which enables people to achieve their maximum personal potential (Seedhouse 1986). Health requires basic necessities to be achieved but also provides the basis for higher human needs, such as caring and self-actualization. Dubos (1959) views health as the ability to adapt to new or changing circumstances. This capacity is seen as a fundamental human trait, part of which is humankind's ability and willingness to alter the environment or ecosystem for human purposes. The third positive definition is that of the **World Health Organization** (WHO; 1948) in which health is a "state of complete physical and social wellbeing and not merely the absence of disease or infirmity." Finally, Parsons' (1972) definition also emphasizes the ideal, seeing health as "the state of optimum capacity of an individual for the effective performance of the tasks and duties for which he/she has been socialized." All the positive definitions of health emphasize human capacity to function.

Ecosystem Health

Callicott (1992) creates a definition of ecosystem health based on Leopold's concept of land health. For Leopold (a conservationist scientist in the late 1930s and 40s) the concept of land health is associated with structural integrity and the continuity or stability of biotic communities over long periods of time. Callicott suggests that ecosystems displaying order, stability and continuity are healthy, and maintaining land health is as possible and fundamental as the maintenance of human health or the health of a nation's economy. Similarly the definition of Haskell et al. (1992) incorporates Leopold's concepts of stability, sustainability and self-renewal:

> "An ecological system is healthy and free from "distress syndrome" (the irreversible process of system breakdown leading to collapse) if it is stable and sustainable — that is, if it is active and maintains its organization and autonomy over time and is resilient to stress. Ecosystem health is thus closely linked to the idea of sustainability, which is seen to be a comprehensive, multiscale, dynamic measure of system resilience, organization and vigour. Accordingly, a diseased system is one that is not sustainable and will eventually cease to exist (p. 248)."

Parallel to the concept of ecosystem health is the concept of ecosystem (or ecological) integrity. The goal of the Great Lakes Water Quality Agreement (1978) is to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Ecosystem integrity refers to the ability of a natural system to function optimally. It is analogous to the positive definitions of human health. While ecosystem health implies the ability of a natural system to operate under normal environmental conditions, ecosystem integrity implies that the system can maintain an optimal operation point while stressed and can continue evolving and developing through a process of self-organization (Kay 1993).

Scientific Models and Root Metaphors

Scientific inquiry requires structuring observations into a model that allows measurement. The model enhances our understanding of the phenomena of interest, but its validity depends on its ability to predict the behaviour of the system's components as a whole, even if the purpose for constructing the model was not utilitarian. Specific measurements are designated indicators because they reflect the significance of a particular characteristic within the model or encapsulate the predictive power of the model. Hunsaker and Carpenter (1990) define an environmental indicator as "a characteristic of the environment that, when measured, quantifies the magnitude of *stress*, habitat characteristics, degree of *exposure* to a *stressor*, or degree of ecological *response* to the exposure" (emphases added). Underpinning this approach to indicators are conceptualizations identified by the IJC (1991), namely self-maintenance or self-sustainability of ecological systems, sustained use of the ecosystem for economic or other social purposes and sustained development to ensure human welfare. But goal or use -- the purpose of the indicator, what it is meant to measure -- is determined by the a priori model of how the world (society, environment or whatever) works. We must constantly be aware that indicators derive from models and depend on the nature of the models themselves.

In the case of ecosystem health, "health" is a word normally applied to human *individuals* that is applied to ecosystems as entities encompassing interconnected populations of many species. In its broadest sense, such a metaphor is seeing something from the viewpoint of something else (Brown 1977), involving transferring one term from one system or level of meaning to another. It works when that term is consciously used in a different context. Thus metaphors must not only be significant but must also pretend not to be literally absurd. This is especially the case with root metaphors which put forward fundamental images and values about the world. Ecosystem health is such a metaphor, with fundamental, psychological importance linked to self (through health) and holism (through ecosystem).

Both models and metaphors describe human experience and encapsulate human observations, but they do so differently. Models capture those elements that can be measured, that are quantifiable. Metaphors capture those elements that enrich our understanding in one area by analogy with another area, but cannot be measured. Scientific models ultimately are mathematical relationships and give us the power of prediction of how the system will behave. Metaphors capture the similarities between things but they are not inherent properties of the systems being described. Models and metaphors are both derived a priori from our understanding of the world. Both represent strongly held beliefs about how the world operates.

Their difference lies in their testability: a scientific model is meant to be testable and falsifiable whereas a metaphor is part of a world view, challengeable only by revolutions in thought. Yet if we accept Allen and Hoekstra's (1992) view that observational techniques are filters, then it is important to understand the "humanness" of models. Models have meaning only in the context of the "boundaries of science" and their meaning is dependent not just on their findings but on the form of the model itself: its scientific code. Thus as Bateson (1972) argued, the structure of meaning is dependent on the code and how that is transformed into a message (scientific findings). If we share a code (a scientific model), we can understand missing parts — they are intelligible because we use the code to make sure all parts of the message fit.

"Measuring" Ecosystem Health

The issue therefore is whether health can be more than just a metaphor, but also a measurable property of ecosystems. Much of the literature employing the concept of ecosystem health (e.g. Rapport 1989; 1992; CPHA 1992; Allen et al. 1993) relies on ecological principles of: 1) organismic theory (of Clements 1905), which has been abandoned by most ecologists (Ehrenfeld 1992); and 2) stability, succession, diversity which have been further challenged by the "new" ecology (Shrader-Frechette and McCoy, 1993; Zimmerman 1994). An ecosystem health model, rather than metaphor, would require that ecologists can distinguish between a healthy and a diseased ecosystem just as a physician can distinguish between a patient who is healthy or ill. But, as Ehrenfeld (1992, 137) explains:

> "[if] communities have fixed identities, [if] they are normative like organisms, we can easily apply the normative idea of health to them: if they are functionally and structurally similar to their abstract ideal, they are healthy; if they deviate significantly they are sick. If the idea that communities have a normative, equilibrium position, a balance point, were still widely accepted, then the idea of ecological health would pose few problems . . . but ecological concepts change . . . no longer are communities considered normative."

Kelly and Harwell (1990) lament that the analogy of ecological health to human health is strained, given that ecosystems are far more complex than human metabolism; exposure of an ecosystem to external disturbance often means differential exposure to only loosely connected parts of the system. Human tissues and organs, on the other hand, are strongly internally coordinated and highly interdependent.

Even with a characteristic set of normative ecosystem ideals, the health concept would still prove problematic. Just as the definitions of human health can vary between individuals, across cultures and over time, so can they vary for ecosystem health. The uncritical application of the concepts of ecosystem health and/or integrity can lead to the application of "medical diagnoses" to achieve an agreed upon state of "health." The "new ecology" (a term applied to describe a major theoretical shift in the field of biological ecology) which calls attention to the instability, disequilibria and chaotic fluctuations of environmental systems (Zimmerman 1994) may in fact make the ecosystem health concept problematic in scientific application. Although it may resonate with environmental action and policy debate and formulation, both Sagoff (1985) and Schrader-Frechette and McCoy (1993) have drawn attention to uncertainty in ecological science.

However, Fine and Sandstrom (1993) contend that people actually see and understand their world through simple slogans and metaphors like "ecosystem health," not through any complicated theories. Ecosystem health as a metaphor provides a commanding image of environmental concern in our ecological times (Worthington 1983) and the *normative* and personal nature of the health concept. Scientists respond to metaphor in much the same way as the general public (Gieryn 1983). They are guided by dominant cultural images in deciding suitable topics for research and in constructing limits around the "boundaries of science," which are of course also shaped by how observations can occur. The ecosystem health metaphor has indeed served as a point of departure, and as an important heuristic tool for scientific investigation into environmental *diagnoses* and *prescriptions* in general, and in the case of the North American Great Lakes in particular. For scientists and the lay public alike, the ecosystem health metaphor provides a method of common engagement, a "metaphorical resource" (Fine and Sandstrom, 1993, 26), packed with shared meaning and normative direction, that can be called upon to legitimate a cause or ignite an emotional response. Thus the ecosystem health metaphor encapsulates both the ecosystem approach to human health and as well, some notion that an ecosystem, like an organism, can react negatively to some external stressor and become diseased or "unhealthy."

Conclusions

- All indicators are goal-directed; they essentially monitor "system" change given desired outcomes. All indicators (as they are selected from an unknowable universe of all possible indicators) are normative.

- "Ecosystem" and/or "environment" is a core value of interest in the identity formation and concerns of populations in the Great Lake basin.

- The value sets that determine indicator selection for ecosystem health and human health should be clearly defined for any developed set of indicators.

2.2.2 Human Impacts on the Ecosystem

The 20th Century has brought an increasing role for the physical and chemical sciences. Elucidation of temperature gradients and basic chemical parameters in water bodies was among the first descriptive work. For toxic substances in environmental media, methods have developed to quantify levels of gases, particulates and organic compounds in air (e.g. Ministry of Environment and Energy 1994) and a wide range of traditional inorganic (e.g. mercury) and organic compounds (e.g. combustion products) in soil and sediment. In water, sampling methods permit collection at distinct points within water columns of dissolved substances (e.g. phosphates), chemicals adsorbed to suspended particles (e.g. PAHs) and functional properties (e.g. biochemical oxygen demand).

Chemical analyses with increasing sensitivity have also enabled measurement of contaminants in many biological tissues of species that make up the food web (Environment Canada, Fisheries and Oceans, and Health Canada, 1991). Monitoring organochlorine pesticides and their metabolites in the fat of fish and bird species along with human foods, fat samples and breastmilk was initiated during the 1960s in response to local use and aerial transport of DDT. Neurotoxic metals also became important: mercury, because of the discovery of the role free-living bacteria play in transforming it to methyl mercury, increasing its bioavailability and subsequent concentration up the food chain; and lead because of its widespread dissemination as a gasoline additive.

Together these data on media and species have permitted sophisticated modelling of contaminant sources and movements within the ecosystem (e.g. review by McKay and Patterson, 1992). For biological species within a toxicological framework they provide the raw material to determine exposure to toxic substances, including calculations of dose based on the various routes of entry. Yet, after some of the more dramatic cases of contamination were mitigated (e.g. phosphate loading), the task of ascription of causal relationships between ecosystem observations and past or present human activities has become increasingly challenging, because of the complexity of ecosystem relationships and the political and economic implications involved.

While the increasing impact of humankind cannot be doubted (see Goudie 1994), nor should the power of human invention and innovation. In studying the effect of human activity on ecosystems, we must, therefore, not only examine the ecosystem but human adaptability as well. A focus of ecological anthropology (e.g. Geertz 1963; Vayda and Rappaport, 1976) is based on Steward's (1955, 1978) ideas on the causal connections between social structure and way of life. The nature and rate of environmental change (often degradation) cannot be divorced from this way of life, including needs, wants, technology and values.

Why does human activity in an environment take the form it does? This is a vital question for advocating particular changes in activity for ecosystem "protection." Further, the form of activity is predicated on how a people perceive resources and their relationship to the environment. There are several ways to perceive that relationship; Kluckhohn (1953) suggests three:

- people as subjugated to nature, living at the mercy of a powerful and dominant environment
- people as over nature, dominating, exploiting and controlling the environment
- people as an inherent part of nature, trying to live in harmony with nature.

In the Great Lakes area, tension exists between the second and third, although it may be easier to understand the present status of the debate over ecosystem by asserting that the tension is exacerbated by the fear of the first, especially with respect to human health and wellbeing if control over our affairs is apparently reduced to the demands of ecosystem health.

These concerns are often considered when credible scenarios of potential outcomes are expressed using a range of tools. Ecological risk assessment and the more legally bound, environmental impact assessment, are increasingly being carried out on a wide range of human development projects and interventions. These tools permit explicit examination of trade-offs between human-oriented outcomes and environmental impacts. Although often cast in traditional cost-benefit terms with the cost of mitigation procedures weighed against the benefits of the particular development, other approaches to incorporating human interests and values in ecosystems are increasingly advocated (Public Health Coalition 1992). Ecological economics is one emerging field that questions the usual micro-economics approaches to valuations in development (Costanza et al. 1991). Among its practitioners, Daly (1991) has argued for the need to estimate and set limits on the maximum scale of human development activities possible within particular ecosystems up to the global scale.

If values are important in understanding how human activity affects the environment, it is perhaps also necessary to examine environment as a value in relation to other values and life-domains. Environment tends not to be valued highly in relation to other domains, such as family income and standard of living that are most highly valued (Eyles 1985; 1990). In one investigation in which people were asked the defining characteristics of where they lived, environment trailed such dimensions as social relationships, economic wellbeing, memories, roots, and even no opinion and nothing (Eyles 1985). This ranking reflects a lack of understanding that all of the valued dimensions depend ultimately on the environment.

Environment or ecosystem does not then necessarily engage significant life-domains or core values. The issue can, however, be considered differently. When does environment engage us? And what values are expressed? Our answers can only be suggestive. First, we are engaged when we are threatened. Edelstein (1988) in his work on contaminated communities makes the useful distinction between lifestyle and lifescape, the former referring to people's way of living, the latter to our fundamental understandings about what to expect from the world around us — our social paradigm. When lifescape is threatened, core values are threatened. These ideas have not been fully developed, although some research suggests they include those things that indicate threats to our children's health, property values, fear of unknown, latent health effects (Eyles et al. 1993).

Second, the values expressed in environmental concern are again not well-articulated in empirical research. There has been some use of "altruism" to explain intentions to ameliorate environmental problems (Black et al. 1985). As Stern et al. (1993) explain, "Altruism suggests that pro-environmental behaviour becomes more probable when an individual is aware of harmful consequences to others from a state of the environment and when that person ascribes responsibility to her/himself for changing the offending environmental condition." This is but one value orientation. Others include "the land ethic," which emphasizes the welfare of non-human species (Heberlein 1972) or of the biosphere itself, as in deep ecology (Devall and Sessions, 1985). Still others implicate economic and socio-biological orientations (Hardin 1968; Olson 1965). Altruism seems the most likely value basis for environmental concern. Through it, concerns for the ecosystem are linked to concerns for other humans. Implicated in it are other fundamental human values such as community, equity and justice. Thus ecosystem health is indirectly pursued through human actions directed at humankind. But, this emphasis on ecosystem health through altruism is but one value orientation, and it is a fragile commitment. Human activity is geared toward human betterment, health and wellbeing. However, those who perceive the dependence of these on the environment tend to have strong environmental concerns and values.

Human choices are not free of the limits imposed by being part of the ecosystem. We cannot choose whatever kind of world we want. We can and do have models of the impact of human activities on ecosystems and the predictable consequences for humans if the ecosystem shifts from one state to another, e.g. arable land to desert or forest to eroded hillside. It is a human value choice whether we attempt to extend the lifespan of the human species, as much as possible, or view the human good as the maximum potentiation of the present -- getting the most out of our environment as it is now. The moral issue is not the extinction of the human species; the species will become extinct sooner or later. Rather, it is whether the extinction is at human hands or by natural forces, not the number of premature human deaths involved in the extinction process. The ethical issue is the lifespan of the species, the number of generations that enjoy this planet earth before the extinction occurs.

Human health, especially the positive definitions of human health, focus on the individual. The maximum potentiation of humans alive today may result in the rapid extinction of the species. A fundamental flaw with the concept of ecosystem health as the value for environmentalists to champion lies in the concept of human health itself. And yet human beings have devised social systems which incorporate societal as well as individual values. Environmentalists tend to extend these societal concerns to include concerns for other species. In the long run, human welfare depends on these species.

Conclusions

- Separate indicators of ecosystem health and human health are required since their goals and targets are different, in the former case ecosystem stability, persistence or resilience, in the latter the disease or illness state of individuals.
- There is a link, however, between indicators of the health of human populations (public health) and indicators of ecosystem health.

2.2.3 Environmental Burden of Illness

As stated earlier, human health can be defined positively and negatively. In a negative sense it can be considered an absence of disease (defined against objective/medical criteria of pathological processes), or an absence of illness (defined by the experience of the individual). In this section we will address the evidence for effects on health as an absence of disease related to exposure to environmental agents.

The evidence for an effect on health comes from environmental epidemiological studies when available. Such studies are limited by the difficulties in assessing the exposures to toxic agents at environmental exposure levels (i.e. accurately classifying who is relatively highly exposed and who is not). All epidemiological studies examine the difference in health outcomes between those who are highly exposed and those who have low exposure to the agent of concern. If a gradient of exposure cannot be found, epidemiological methods are useless, even though the consequences of the exposure may be very real and very severe. Consider the difficulty in knowing whether smoking was related to lung cancer if everyone smoked 20 cigarettes a day. Even if there is a gradient of exposure, we have to be able to correctly classify those who are highly exposed and those with low exposure to get some reasonable measure of the exposures. Otherwise the misclassification of exposure will lead to false negative results in studies. It is quite possible that some widely dispersed pollutants in the environment are having effects we cannot detect epidemiologically for precisely these reasons.

Epidemiological studies also require that the outcome — the health effect — be measured accurately. Much of the concern regarding environmental exposures relates to subtle effects — influences on neurobehavioural development, IQ, psychosexual development and fertility — that may be significant if they occur broadly throughout the whole population, although the impact or deficit for an individual is of little consequence. Other outcomes are of high significance for the individual — cancers, birth defects — but are at low risk at environmental levels of exposure. Because these outcomes can be caused by many factors, it is often difficult to determine if an environmental factor is adding to the burden of illness. Overlapping exposures, all of which in themselves seem to increase the risk of a particular symptom, would seem together to account for more than 100 percent of increases in symptoms. Appropriate statistical techniques must be used to adjust for the lack of independence between exposures, and interactions between exposures and personal characteristics (see Walters 1983). The criteria to assess environmental epidemiological studies are found in Table 1 (Frank et al. 1988).

Environmental health risks can also be estimated by risk assessment protocols using animal data on cancer and birth defect risks. In some situations health effects that have manifested themselves in occupational settings can reasonably be extrapolated back to environmental exposures. More importantly occupational epidemiology often confirms that health outcomes seen in animals will occur in humans if exposure is high enough. For example, Friberg (1984) discusses the evidence for the effect of cadmium on the kidney-linking animal and occupational health data.

The environmental burden of illness refers to the proportion of illnesses, of particular health outcomes that can be attributed to particular environmental exposures. If the relative risk of an outcome occurring in exposed individuals is known and the prevalence of exposure is known, the risk attribution to the exposure in the population, the population attributable risk, can be calculated. We will limit this discussion to the impacts that are or may be occurring in human populations living in the Great Lakes basin as a result of exposures in the ambient environment (exposure to outdoor air, drinking water, recreational water use, exposures to soil) or mediated by the ambient environment (exposure through food). We have included those toxic substances in this section for which there is good evidence for the health effects outlined and for which significant exposure and/or community concern exists in the Great Lakes basin. This section is not an exhaustive review of the evidence on any of

Table 1.

Criteria for the Evaluation of Epidemiological Studies Linking Environmental Toxicant Exposures and Health Effects

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1. **Basic design of study**
   (a) What type of study was used (cohort, case-control, ecologic)?
   - strengths
   - weaknesses
2. **Exposure assessment**
   (a) Is the nature of the suspected exposure known?
   (b) Is the overall dose known?
   - timing and duration of exposure
   - route of exposure
   - body burden

   (c) Is a dose gradient known? How accurate is (are) the exposure category(ies)?
   (d) Were controls used? How accurate is the non-exposed (or non-diseased) classification?
3. **Outcome assessment (measurement of health effect)**
   (a) How appropriate to the particular exposure in question is the outcome being studied?
   - Does other human or animal evidence relate the health effect to suspected exposure? How strong is it?
   - Is the outcome assessment appropriately timed (latency period considered)?
   - Is the health effect examined validated as adversely affecting human health?

   (b) How accurate is the outcome assessment?
   - completeness (few false negatives)
   - correctness (few false positives)

   (c) Is there possible bias in the ascertainment of the health outcome for the various exposure category(ies) and controls?
4. **Control for other factors influencing outcome**
   (a) Are the exposed category(ies) - or cases, in a case control study - and controls comparable (except for exposure)?
   - nature of underlying populations
   - sampling bias

   (b) How great is the problem of confounders likely to be?
   - specificity of health outcome studied for the particular exposure

   (c) How successfully were possible confounders controlled for?
   - adequacy of matching or adjustment of all possible confounders (age, sex, socio-economic status, ethnicity, other exposures to toxicants, access to medical care, secular time trends)
5. **Strength of association between exposure and outcome (relative risk)**
   (a) Does the relative risk have clinical or practical significance?
   (b) Does the relative risk have statistical significance?
   (c) Was a clearcut dose-response gradient demonstrated?
   (d) If no statistically significant relative risk exposure was found, was the statistical power of the study adequate to find a risk of practical importance if it existed?
6. **Evaluation of final conclusion**
   (a) If the result is positive, could it be a false positive association?
   (b) If the result is negative, could it be a false negative association?
   (c) Is the result consistent with other well-conducted studies of the same association and/or related epidemiological knowledge on the distribution and dynamics of the health outcome or condition in question?

Source: Frank et al. (1988, 138) from lower-level exposures in the ambient environment.

the health effects listed. It is meant to cover those areas for which further research and prudent action is recommended. Health effects related to occupational exposures, indoor air quality (except radon), or major environmental disasters are not considered. These exposures can, however, be instructive with respect to risks that may be present from lower-level exposures in the ambient environment. Unfortunately, little precise information exists on exposures to toxic chemicals through the ambient environment in the Great Lakes basin.

Exposure to ozone and particulate (PM-10, i.e. particulate matter of 10 µm or less), especially sulphate particulate is widespread in the Great Lakes basin. Attributable risk estimates for the role of air pollution in hospital admissions and deaths for cardio-respiratory illnesses have advanced considerably over the past decade. A series of studies, including one in Detroit, have failed to detect a threshold for increases in deaths associated with small increases in particulates that can be inhaled fully into the lungs (particulate matter of 10 µm or less, PM-10) (Schwartz 1991). Similarly, subjecting environmental data on air pollution and hospital admission data to advance-time series analyses, Burnett et al. (1994) showed the increases above baseline admission rates attributable to ambient air pollution, ozone and sulphates in particular. Sulphates in air are widely monitored in Ontario, but sulphate may be an indicator of acid aerosol or PM-10 exposure, rather than sulphate itself causing the effect. This effect was present only for the warm months of May through August. Infants up to one year of age were the most affected, with 14.8% of all admissions for respiratory illnesses to hospitals in Ontario attributable to ozone or sulphate exposure. This study has generated the best attributable risk estimates for an ambient environmental exposure of any study in the Great Lakes basin. Given its major role in environmental burden of illness, extrapolation of these figures to particular Areas of Concern should be possible based on local air pollution data collected by provincial or state authorities.

The second most general ambient exposure of concern is exposure to certain organic compounds and metals in the air of the major industrial cities of the basin. In this case, risk assessment methodology generates estimates of cancer risks related to lifetime exposure. Comparison to total population risks for particular cancers (up to 10 percent for some cancers) reveals that the proportion attributable to individual air toxics is very small, not exceeding 1/10 of one percent. Given the large population exposed to the risks associated with a number of these compounds, their presence in our air is a public health concern. Cancer risks related to these air pollutants are well covered in the Windsor Air Quality Study (MOEE 1994) and the review of the outdoor air quality in the City of Toronto (Campbell 1993). The agents in the Windsor study with the major portion of the cancer risk range greater than one in 100,000 for lifetime exposure as an outdoor air pollutant are benzene, 1,3-butadiene (from car exhaust) and chromium VI. Cancer risks for diesel fumes are well established (Carey 1987) but the risk at ambient levels of exposure is unknown. Radon gas comes from the natural environment into homes and buildings and concentrates in indoor air. There is a very low risk of lung cancer from this indoor exposure, which has been difficult to demonstrate in epidemiological studies (Lubin 1994). Radon could be a problem in the portion of the Great Lakes basin that is on the Canadian shield, but it is also a community concern in the Port Hope area.

A considerable body of toxicological and epidemiological data has developed because of the stakes involved for the producers of chemicals and those exposed to chemicals, particularly in occupational settings. Higginson (1992) reviewed studies attributing portions of the cancer burden to different factors, but pointed out gaps on exposure information that required considerable assumptions to produce estimates, particularly with respect to physical environment and non-occupational exposures.

Expert groups, such as that brought together by the International Agency on Research in Cancer, have estimated the theoretical preventability of cancers (Tomatis 1990). Miller (1992) carried out a similar process for Canada, examining a series of actions that might reduce cancer incidence and comparing the reductions to those that are potentially preventable, based on intercountry comparisons of incidence. Melanoma from ultra-violet radiation stands out (40% reduction), although uv-B exposure is only one factor related to melanoma risk. The thinning of the ozone layer over the Great Lakes basin may be associated with increases in skin cancer and cataracts over time, but these effects have not yet been documented. We do not know the trend in personal exposure to sunlight in the Great Lakes basin, but the role of ultraviolet exposure from sunlight in skin cancer is well established (Ontario Task Force on the Primary Prevention of Cancer 1995).

Trihalomethanes are known to be carcinogenic in animals and are generated in the chlorination process for drinking water. The strongest evidence with respect to drinking water is increased risk of bladder and rectal cancer (Morris et al. 1992), but the carcinogenicity of chlorinated drinking water for humans cannot be considered proven. The major public health benefits of treating water with chlorination are well recognized (see Bellar et al. 1974; Morris et al. 1992); the same authors establish the carcinogenicity of trihalomethanes, using a meta-analytic approach based on case-control studies. The proportion attributable to drinking water would be very low, but most of the Great Lakes basin population drinks chlorinated water. An association between cancer incidence and water supply trihalomethane concentrations has yet to be demonstrated in a Great Lake state or Ontario (Gilman et al. 1992), partly due to the variable sources of drinking water among Great Lakes populations. Nevertheless, further exploration of the risks and benefits to human health of chlorination and its alternatives is clearly warranted.

Tritium is a hazardous substance in areas adjacent to nuclear power plants in Canada because of the use of heavy water in CANDU reactors (ACES 1994). The **Advisory Committee on Environmental Standards** (ACES) in Ontario recommended that the objective for tritium in water be immediately reduced to 100 becquerels/litre (in response to the recommendation by the Ontario Ministry of Environment and Energy to reduce the current objective of 40,000 Bq/L to 7,000 Bq/L) and be further reduced to 20 Bq/L within five years. Tritium concentrations in some Ontario drinking water supplies currently exceed the 20 Bq/L standard from time to time. This recommendation was made on the basis that tritium is a human carcinogen and that the same level of acceptable risk should be applied to it as to other chemicals that are human carcinogens. Exposure occurs through drinking water but also occurs through air and the food chain.

Diseases involving stomach and intestinal infection due to foods and water contaminated by micro-organisms are another major category for which attribution to environmental exposures is routinely made by public health authorities (Todd 1991). Outbreaks from contamination of municipal water supply systems by recently recognized protozoa (e.g. Moorehead et al. 1990) have constituted the largest clearly identifiable human burden of acute illness based on use of water from the Great Lakes or waters flowing into them. Both Milwaukee (MacKenzie et al. 1994), drawing from Lake Michigan, and Waterloo, drawing from the Grand River which flows into Lake Erie, have experienced difficult-to-control outbreaks of contamination by cryptosporidium species. These outbreaks are linked to contamination sources within watersheds that cannot be managed efficiently and effectively at the point of water treatment plants, but are better dealt with by watershed management schemes. Small outbreaks of giardia (another protozoan) and viral diseases such as hepatitis-A do occur, usually transmitted through food (Todd 1991). Giardia is consistently present in some wellwater supplies. Viral diseases transmitted through food in the Great Lakes basin are almost always imported, i.e. acquired by the initial case outside the basin. Exposures to sewage-contaminated waters during bathing (Fleisher et al. 1993) also result in illness, although Great Lakes basin cases are poorly documented.

Emerging literature such as that linking persistent organochlorine pesticide exposure and breast cancer (Wolff et al. 1993) have not been fully incorporated into standard cancer risk estimates, partly due to the ongoing controversy as to the significance of these findings (Ritter 1994; Kreiger et al. 1994). Risk assessment techniques have been used to estimate the cancer impact of eating Great Lakes fish contaminated with persistent organochlorines (Foran et al. 1989). Based on DDT and dieldrin levels in the fish and consumption rates, increases in cancer numbers for various concentrations are calculated. Yet these are difficult to relate to particular areas unless distributions of fish consumption are known; such data are often of variable quality and representativeness (Ebert et al. 1994).

The established effect of dioxins in animal models and the probable effect of DDT, PCBs and other persistent organochlorines on the immune system are likely to be an endocrine modulation effect (see Chapter 2.4). Exposure to dioxin is primarily through the food pathway because of distribution through the atmosphere (Davies 1988). Reliable risk estimates associated with this exposure are not available.

There is significant public concern regarding exposure to currently used pesticides. Organophosphate pesticides are used in institutions such as to control pests like cockroaches. Although case reports for health effects related to exposure do exist, these effects in the majority of the concerned population likely fall in the category of environmental hypersensitivity (see below). There is evidence that aldicarb, a carbamate pesticide, may impair immune function (Fiore et al. 1986). This exposure has occurred through well-water in Wisconsin. The **International Agency for Research on Cancer** (IARC) has classified several herbicides as possible human carcinogens and the recent report of the Ontario Task Force on the Primary Prevention of Cancer (1995) has recommended reasonable and measurable timetables to sunset these herbicides. Some fungicides have been shown to be carcinogenic in animals and significant exposure can occur through food, such as the consumption of pick-your-own strawberries (Mitchell et al. 1987). Use of these fungicides is now restricted in Canada and the United States.

Recent concern has focussed on neurobehavioural deficits resulting from in-utero exposure to persistent toxic substances. The effect of low levels of lead exposure are now well established (Needleman and Bellinger, 1991). Mercury is known from environmental disasters to produce neurobehavioural deficits in children, and modelling of fish consumption and methylmercury intake is feasible (Richardson and Currie, 1993). Epidemiological methods have not established effects in the Great Lakes basin. The role that aluminum exposure, primarily through drinking water, may have in the development of Alzheimer's Disease has been extensively reviewed (Nieboer et al. 1993), and although there are major weaknesses in the epidemiological evidence, a possible role cannot be ruled out by other scientific evidence. Infants of PCB-contaminated, fish-consuming mothers were smaller than controls and had behavioural deficits and impaired visual recognition (Fein et al. 1984; Jacobson et al. 1984; Jacobson and Jacobson, 1988), but the significance of these findings is still debated. Several research projects in progress in the basin are attempting to resolve this issue (ATSDR 1994). Limited evidence exists for direct neurotoxic effects related to exposure to organic solvents from waste dumps (e.g. Hertzman et al. 1987).

Determining the burden of reproductive problems expected at the levels of exposure thought to exist among human populations in the Great Lakes basin is fraught with uncertainties that have been highlighted in the Commission's *Seventh Biennial Report* (IJC 1994). Reproductive outcomes refer to birth defects and to the impact on fertility. Cadmium, lead, mercury and chlorinated solvents are toxic to human reproduction, but at levels considerably above those found through environmental exposure in the basin. Controversy has surrounded the attribution of reported reductions of sperm counts in industrialized countries to increasing exposure to exogenous (from outside the human body) estrogens such as nonophenols, phthalates and persistent organochlorines (Carlsen et al. 1992; Bromwich et al. 1994). Studies are underway to examine contaminant levels in a range of angler, minority and other populations in the basin (ATSDR 1994) and new sensitive outcomes are being examined in relation to these levels (e.g. time to pregnancy). Some potential health effects such as changing the frequency of behaviours more common in boys or girls (dimorphic behaviours) due to environmental estrogens still remain unexamined.

It is beyond this scope of this discussion to outline the burden of illness related to environmental hypersensitivity. This illness has been increasingly attributed to physical environments (Ashford and Miller, 1991) but is likely associated with specific social environments as well. A set of psycho-social impacts (stress, anxiety, worry) may not be recognized as "disease" but may be significant in experiencing an environmental exposure (Edelstein 1988; Taylor et al. 1993). Other interpretive models than traditional epidemiological ones are required to understand the linkages between such experienced "illnesses" and ecosystem parameters. Other investigative methods, based on qualitative traditions, are also required (Eyles et al. 1993).

Indicators of Environmental Burden of Illness

It would be useful to determine the magnitude and trends in the impact of environmental factors on human health outcomes. A wide variety of morbidity and mortality statistics are kept, which are useful in health care service planning. These data do not, however, reveal the cause of the health effect. All health outcomes have a multitude of causes or risk factors; environmental agents are but one contributing factor. Several approaches have been tried to isolate the attributable risk associated with the environment (Walters 1983).

Cancer and birth defect data have been mapped in atlases (Gilman et al. 1992; Johnson et al. 1992; Mills and Semenciw, 1992). Geographic patterns do emerge in these atlases, but it is not only environmental risk factors that vary geographically. Rather than the atlas giving answers that the high rate of cancers or birth defects in a particular area is likely due to particular environmental conditions, we usually can explain the variation on the basis of what we already know about the risk factors for the specific health effects. Atlases, however, can at times be useful to generate a hypotheses to test by other means.

Cancer outcomes are poor indicators of environmental effect because the latency between exposure and outcome is usually several decades. The exception to this general rule is the use of childhood leukemia as an endpoint for exposures to radionuclides. The latency for some leukemias is two to ten years. Studies of the association between proximity to nuclear power plants and leukemia have shown a slight (but not statistically significant) trend toward increased leukemias (Clarke et al. 1991).

Birth defects (minor and major) occur in three to four percent of all pregnancies in Ontario (Mills and Semenciw 1992). Some of this effect is related to background exposure to teratogens, including radiation in the environment and naturally occurring chemicals in food. Although birth defects are relatively common, they are not good indicators of effect related to toxic agents added to the environment by human activities. There are a wide variety of birth defects and the effect of any specific agent will be only at critical stages in the development of the embryo. Individual types of birth defects have a low incidence in any geographic area. An environmental exposure over a relatively small geographic area, even if it were a strong teratogen, would produce few specific birth defects over a short period of several years. The increase in outcome will be less than the chance variation in outcome and thus not be detectable by epidemiological methods.

In some situations the environmental effect of a pollutant is the major source of variation in the health outcome. Thus a clear association between hospital admissions for asthma and respiratory problems has been demonstrated related to particulate, ozone and sulphate pollutants in the air (Burnett et al. 1994; Dockery and Pope, 1994). Indeed this effect varies directly with air pollution levels without evidence of a threshold. Hospital admissions for children under one year show the effect most clearly, and thus these hospital admissions would make a good indicator of the respiratory burden of illness. The lag time for the effect is up to three days. Compare this to several decades' latency for lung cancer and it is clear why trends in lung cancer do not give a good indication of effects related to those air pollutants that clearly do add to the burden of lung cancer.

Although the increased exposure to uv-B in the Great Lakes basin because of thinning of the ozone layer should result in increased skin cancers (squamous and basal cell carcinomas) and cataracts, this effect may also be moderated by measures individuals take to reduce their exposure. Skin cancers and cataracts have long latency periods, so that today's trends represent the effect of environmental and behaviour changes several decades ago. Trends in these outcomes deserve study, but they do not serve well as indicators of how our environment is doing today.

The practical reality is that the association of low-level environmental exposures to health effects can rarely be established by epidemiological methods. Risk assessment methods can give reasonable estimates of risk at levels of exposure in the ambient environment. The limitations of science, however, do not mean that health effects related to ambient environmental exposure are not occurring or are not of concern (see Chapter 2.4). For some toxic substances like lead, very good evidence from well-controlled epidemiological studies and/or risk assessments indicate that health effects are or very likely are occurring within the range of ambient exposure. In these situations, the most practical way of determining the trend in the environmental burden of illness then becomes measurement of the change in exposure, not measurement of the health outcome. Blood lead surveys have routinely been done for this purpose. The neurobehavioural impact of low levels of blood lead has been established in cohort studies (Needleman and Bellinger, 1991). Population surveys of blood lead levels in children can then establish the likely environmental health impact from lead. Population surveys of children's IQ and measurement of environmental concentrations of lead (air lead, soil lead) would never be able to establish the environmental burden of illness. Blood lead is a much better indicator of actual received dose than measures outside the body. Children's IQ is influenced by a wide variety of factors that, in general population monitoring would override any clear indication of a lead effect. Monitoring of other persistent toxic substances (such as PCBs in human tissues) would similarly be useful.

Blood lead is one example of a bioindicator, a measure of exposure. Bioindicators can also measure physiological changes as a result of exposure. Environmental agents are, however, not specific in producing these changes, so that the actual application of bioindicators of effect in Great Lakes basin studies has not proved to be useful (Kearney and Cole, personal communication).

What can summarize the best measures to monitor the potential of environmental exposures to produce human health effects are the actual monitoring of the agents known to produce the direct effects. Further studies of toxics in food similar to Davies (1988) are warranted. Blood lead surveys are appropriate, but with the elimination of lead in gasoline, lead exposure has become a less serious issue in the Great Lakes basin. A case can be made for creating a database to monitor persistent organochlorines in the population, but this recommendation may be influenced by the outcomes of current ATSDR-funded studies on PCBs and neurobehavioural effects (whether or not the results of the Michigan fisheater cohort studies are confirmed). New research on endocrine modulators is needed (see Chapter 2.4). Until there is a much clearer understanding of the effects of these chemicals, better characterization of exposure (serum total PCBs likely being the most cost effective and representative measure) is warranted.

In terms of actual effects of toxic agents in the environment on the health of humans in the Great Lakes basin, hospital admissions for children under one year of age for asthma/respiratory disease is the only precisely measurable indicator at this time.

2.2.4 Indicator Selection Criteria

Various attempts have been made to establish lists of criteria for indicators, recognizing that no single indicator is likely to meet all the criteria. The Council of Great Lakes Research Managers developed 16 criteria for indicators of ecosystem health (IJC 1991; see Table 2). In the report, ***Bioindicators as a Measure of Success for Virtual Elimination of Persistent Toxic***

Table 2:
Ecosystem Health Indicator Selection Criteria Developed by the Council of Great Lakes Research Managers

Biologically relevant	• • • i.e. important in maintaining a balanced biological community
Socially relevant	• • • of obvious value to and observable by shareholders or predictive of a measure that is . . .
Sensitive	• • • to stressors without an all-or non-response or extreme natural variability
Broadly applicable	• • • to many stressors or sites
Diagnostic	• • • of the particular stressor causing the problem
Measurable	• • • i.e. capable of being operationally defined and measured, using a standard procedure with documented performance and low measurement error
Interpretable	• • • i.e. capable of distinguishing acceptable from unacceptable conditions in a scientifically and legally defensible way
Cost-effective	• • • i.e. inexpensive to measure, providing the maximum amount of information per unit effort
Integrative	• • • summarizing information from many unmeasured indicators, one for which . . .
Historical data are available	• • • to define nominative variability, trends and possibly acceptable and unacceptable conditions
Anticipatory	• • • i.e. capable of providing an indication of degradation before serious harm has occurred, early warning
Nondestructive	• • • of the ecosystem, one with potential for . . .
Continuity	• • • in measurement over time, of an . . .
Appropriate scale	• • • for the management problem being addressed. For the International Joint Commission, there are three relevant spatial scales: the Area of Concern, lakewide management and the basin ecosystem and many appropriate temporal scales
Not redundant with other measured indicators	• • • i.e. providing unique information
Timely	• • • i.e. providing information quickly enough to initiate effective management action before unacceptable damage has occurred

Substances (1994) submitted to the IJC's Virtual Elimination Task Force (VETF), four criteria are suggested: specificity to the substances; placement in appropriate scales; ease and cost of measurement; and social relevance/public perception. This is a sensible short list. Eyles and Cole (1995) in their monograph use a simplified but more generic approach to indicator criteria applicable to ecosystems and human health. They propose two sets of indicator criteria: science based and use based, with the caveat that all indicators are goal directed and that good indicator selection is dependent on specifying the problem to be measured and managed. The science-based criteria are:

- **Data availability and suitability.** It is likely because of cost constraints that existing datasets must be used where possible, but it must be remembered that those data may have been collected for different purposes than now required.

- **Validity and reliability.** To be valid, an indicator must measure the phenomenon or concepts it is intended to measure. There are four types of validity:

  - Face validity (after evaluating the rationale behind indicator selection, is it a reasonable measure?)
  - Construct validity (does the measure behave as expected in relation to other variables in the scientific model in which it is being used?)
  - Predictive validity (does the measure correctly predict a situation which would be caused by the phenomenon being measured?)
  - Convergent validity (do several measures collected or structured in different ways all move similarly over time?)

  Reliability depends on the amount of error variance in an indicator measurement, and is determined by carrying out repeat measures of the same indicator.

- **Indicator representativeness.** Questions of data representativeness are quite easy to recognize, based as they are on sampling procedures, and size and population characteristics. More troublesome is the issue of indicator representativeness. Is it possible to select one or several indicators that cover the important dimensions of concern? Indicator representativeness may be enhanced by developing an index, combining indicators. However, even if the problems of combining indicators can be overcome, if the index rises or falls, it remains unstated which of its constituent indicators are rising or falling.

- **Indicator comparability.** Not only must data be available for several time periods, they must also mean roughly the same thing at those times. The sensitivity of measurement procedures or the nature of the population being studied may change.

- **Disaggregating indicators.** To be informative, indicators must be related to other variables such as age, sex, locale and various characteristics of the involved individuals or communities. If an indicator can be broken down by several variables, it tells us a great deal more, so long as the numbers do not become too small.

The use-based criteria for indicator selection are:

- **Goal oriented.** There should be as much clarity as possible in the definition of the relationship between the indicator and the goal (purpose, use, state) that it is meant to monitor.

- **Feasibility.** Are the data already collected? If they are, are they available for the right time periods and at the desired geographical scale? If they are not, how feasible is it to create surrogate or indirect indicators of the phenomenon of interest? If this is carried out, what happens to scientific validity? If the data are not collected, how expensive would it be to alter the information-gathering system?

- **Desirability.** Do the indicators inform on the state of the ecosystem or of health in ways that are perceived as important by those affected? Do the indicators enable residents of a particular region or the members of a particular population group to assess their needs and risks? Do the indicators enable them to make meaningful comparisons with similar groups of residents or populations members? A feature of desirability is in fact credibility (a user-version of validity).

- **Gameability.** If there is to be a link between public perceptions and indicators, then we must ensure that indicators are not gameable, i.e. that they cannot be "gamed" or altered by those with something to gain (while others lose) from the indicator being pushed in a certain direction at a particular pace. For example, if resources for improvements in water quality are dependent on a particular level of microorganisms, it may pay a municipality to defer reporting improvements until budgetary allocations are made.

- **Manageability.** The ability of human beings to process information is limited. Therefore, the number of indicators to be used should be as small as possible.

- **Balance.** There should be a rough balance among all of the phenomena of interest.

- **Catalyst for action.** We may choose to distinguish indicators that more or less act as catalysts for action, whether on the part of industry, government, communities or individuals. This criterion is also important in that it relates indicators firmly to the goals of monitoring.

These criteria act as criteria for the suitability of indicators in themselves and as criteria for specific indicator selection. They enable those concerned with monitoring ecosystems and human health in the Great Lakes basin to consider matters of proof (primarily, but not exclusively the scientific list) and of prudence (primarily, but not exclusively the use list) together.

2.2.5 Summary

It is necessary to ask continuously: how is human health relevant to the specific ecosystem issues under consideration? What "evidence" (scientific or philosophic) underpins the connection of human health and ecosystem health? How might we judge the significance of any identified connection? In answering such questions through identifying plausible indicators, we must always be aware of the normative basis and power of science.

We must recognize in our efforts to "measure" ecosystem health and human health as an integral part of it that "ecosystem," health and similar terms are abstracted notions with implications not only for what but also how we measure things. The notions that become powerful, that have resonance, take on metaphorical significance, hence the need for value clarification. We must also recognize that adoption of a prudent or precautionary stance towards the evidence of health effects must be open to scientific evidence. In our use of the metaphor ecosystem health, we must exercise caution concerning the connectionist view of the world contained in the metaphor. The utility of the connectionist, network approach to human health in relation to ecosystem is a framework -- an overarching recognition that warns of possible trade-offs, side effects, possible unintended consequences and unanticipated events. It should not be so overarching that it limits our capacity to act in subsystems or among subpopulations. For this, we must battle the power of metaphor.

Although it is difficult to attribute a specific proportion of overall burden of illness to the environment or ecosystem degradation, human health is a vital consideration in the ecosystem health paradigm. Ecosystem health internalizes human wellbeing as part of the environment, while a human health focus internalizes environment for individual and community wellbeing. The strength of the metaphor or paradigm is clear. Ecosystem health sees humans as integral parts of nature. The metaphors resonate strongly with core values about ourselves, our identify and our place in the world.

2.2.6 Recommendations

- **The Science Advisory Board recommends that the Commission, in its priority activities and its advice to the Parties, support further research to determine ambient levels of exposure to toxic chemicals in the Great Lakes basin and incorporate the following general principles for further development of environmental burden of illness indicators:**
    - continued monitoring of toxins in media, including trihalomethanes, nitrates, microbial contaminants in drinking water, PM-10, ozone and sulphates in air, and toxic bioaccumulative chemicals in general
    - systematic synthesis of water sampling results for microbial contaminants that result in beach closings. Consider complementing these with information on symptoms among beach users
    - inclusion of relevant ambient exposure factors (e.g. time outdoors, based on activity record) and consumption factors (e.g. freshwater fish and wildlife) in population-based health surveys. General population-based measures of body fluid levels of key contaminants (e.g. PCBs or DDE for the organochlorines in serum and breast milk, mercury and lead in whole blood for the metals) could be linked with these and other relevant social factors
    - surveillance of established environmental health outcomes, such as asthma, such that these conditions may be considered as sentinels for pollution effects
    - recognition that some human illness indicators are poorly suited to provide useful information on the impact of environmental matters on human health, e.g. most morbidity and mortality data that is routinely collected, including cancer rates
    - development of longitudinal designs around exposures and conditions of interest to enable stronger inferences concerning relationship between exposure and health outcomes.

It is also recommended that the Commission:

- **support actions that would lower human exposure to persistent toxic substances such as PCBs and lower concentrations of these substances in human tissues.**
- **support the development of indicators and scales that measure the environmental component of illness and wellbeing and indices of environmental stress and environmental condition**
- **continue to monitor state of the environment and sustainable development reporting in order to inform its recommendations to the Parties, regarding Great Lakes basin indicators. As these reports often take a broad-based approach to indicator selection, this monitoring is necessary to help ensure the integration of human exposure considerations into assessments of contamination in relevant fish and wildlife species.**

2.3 WEIGHT OF EVIDENCE: APPROACHES TO DECISIONMAKING IN THE FACE OF UNCERTAINTY

As more and more scientists venture into the arena of public policy, they are proving a valuable point: scientists, no matter how expert at their craft, are no wiser than anyone else when it comes to public policy.

David Sarokin, Washington, D.C. (From: "Letters," *Science*, Vol. 261, September 10, 1993, commenting on the editorial, "Pathological growth of regulations")

2.3.1 Introduction

The *Sixth Biennial Report on Great Lakes Water Quality* of the **International Joint Commission** (IJC), in 1992, proposed as its first recommendation the application of a "weight of evidence" approach to identify and virtually eliminate persistent toxic substances. In that context, weight of evidence referred to considering together the many studies that indicate (or refute) injury or the likelihood of injury, to determine if the evidence is sufficient on which to base conclusions and policy decisions. The Commission elaborated on this proposal in its *Seventh Biennial Report* in 1994, suggesting a "pragmatic" definition drawn from both science and law. This definition noted that the cumulative weight of the many studies that address the question of injury or the likelihood of injury to living organisms should be considered. It was noted that this approach draws on formal science, logic and common sense. Many methodological and definitional questions remained, however. During a workshop at the 1993 Biennial Meeting, Commission members committed to making a priority for the 1993-95 cycle an analysis of how to proceed to clarify these questions. This report is a response to that priority.

Twenty years of experience with very diverse persistent, toxic and bioaccumulative hazards in the Great Lakes basin suggests the need for a systematized approach to evaluating the range of health and ecological effects putatively linked to these environmental exposures. Decisions as to possible measures to prevent or mitigate require explicit methods for dealing with the considerable uncertainty that often exists. Sometimes there is clear evidence of causation, in the form of "mature" epidemiological studies of human health outcomes. These studies can be analyzed by existing or new epidemiological criteria for assessing the quality of evidence on causation, such as those that Sir Austin Bradford Hill first proposed some 30 years ago. Typically, such studies estimate the strength of association between measured exposure to the contaminant and a specific, well-measured human health or natural resources outcome. One example is the evidence in the Great Lakes basin that the organochlorine family of PCBs has induced effects on wildlife. In this case harm to wildlife was observed first, and efforts to identify environmental agents associated with such harm and appropriate abatement measures followed.

However, experience in the Great Lakes also has required consideration of threats to biological diversity from factors other than conventional toxic substances. For these a more systematic and predictive approach is needed. All of the hazards have worrisome features, despite the fact that we do not yet fully understand them. Many toxic substances can lead to cascading complex effects in the Great Lakes Basin Ecosystem, with unpredictable but potentially severe outcomes after a long latent period. Effects can occur at the molecular or cellular level rather quickly, as in the case of estrogen-imitating compounds and we cannot yet evaluate the societal significance of such effects. More often in the past we have waited many years until reproductive failure is widespread among prominent species in the food chain, and at that point mitigation is problematical. Early detection and action are preferable, but that is also the period of greatest uncertainty. In these situations, we have only non-epidemiological evidence (i.e. laboratory studies or modelling) to consider potential harm to humans, animals and/or plant populations. Considerable potential exists for serious problems if longer-term ecological or human health effects are underestimated, and no action is taken to control the substances involved.

To develop criteria that could address these issues, a subgroup of the Workgroup on Ecosystem Health was formed in 1993, to undertake the weight of evidence priority set by the Commission. This term describes a synthetic integration to consider collectively all of the scientific evidence used in decisions to limit the risks from toxic substances. However, in the process of meetings held during 1994, the study group has come to realize that the expression "weight of evidence" is confusing in its similarity to legal scholars' approach to the adjudication of evidence in general, a rather different subject. As a result, the subgroup has, with support of the Workgroup on Ecosystem Health, adopted the subtitle shown above, "Approaches to Decisionmaking in the Face of Uncertainty."

Specific Objectives

Given the above background, this report has the following objectives:

- To review critically the current methodologies for assessing evidence of potential harm to humans or wildlife from putative toxic substances or other environmental interventions as the first step toward decisionmaking

- To identify those characteristics of environmental/human harm from putative toxic or other hazards that warrant adoption of broad, protective decisionmaking approaches

- To recommend, on the basis of this review, appropriate methodologies for assessing current and future Great Lakes environmental hazards as the first steps toward their control or remediation.

2.3.2 Three Methodologies

Three major methodologies have evolved, each of which in its own way systematizes the collection and use of scientific information and assists decisionmakers in the appropriate use and interpretation of that information. These are:

- inference as to causality
- risk assessment
- reports by interdisciplinary expert panels or study commissions.

We examine, comparatively, the strengths and weaknesses of each of these approaches as applied to water quality protection issues in the Great Lakes, particularly in how well a finding can be determined and the uncertainty quantified. The following sections discuss three contexts through which the information is reviewed and incorporated into decisions. This process is referred to in general as risk management.

Inference as to Causality

The steps required to infer causality have been understood since Koch's postulates were developed a century ago for assessing the microbial causation of infectious disease. More recently, Hill's criteria (1965) have been developed for a broad class of health studies. These criteria can be used by scientists not only to identify causal linkage, but often to describe the dose/exposure - response relationship in a mathematical way.

The basic principles of Hill's criteria of causality were developed for human epidemiology. They require that an association between a hazard and effect have most or all of the following characteristics:

Strength of Association. The rate of disease or other health effect in the exposed group of organisms must be higher, in a statistically significant sense[1], than in a control unexposed group -- preferably matched for age, sex, calendar year, etc. The actual strength of the association between hazard exposure and health outcome is measured by **relative risk** (RR): the proportionate increase in the risk of the outcome in question, in the exposed compared to an unexposed group. "Strong" associations have RRs of four or five or more, and are almost always causal in some sense; "moderate" associations (with RRs of two to four) and especially "weak" associations (relative risks of one to two) are often either due to imprecise identification of the exposed group or a non-causal association due to other confounding factors.

Consistency of Association. The same exposure/disease association is found in studies of other populations of the same species separated by geography, time and circumstances. In other words, the observed association is reproducible.

Specificity of Association. The uniqueness of the exposure's health effect is such that it strengthens one's confidence in causality. For example, Minimata disease occurs specifically following mercury poisoning. However, with environmental and other ubiquitous agents, specificity is often difficult or impossible to prove, since so few adverse health effects are caused by only one hazardous exposure. Thus, specificity is helpful when present, but is to be expected rarely.

Temporal Association. Exposure to the hazard must precede the disease or health effect. Latency periods for carcinogenesis (e.g. from smoking) and some other exposure-effect sequences, however, may extend over decades.

Dose-(Risk)-Response Relationship. Exposure increases should lead to stepwise increases in disease incidence or risk. In environmental epidemiological studies, this is often a crucial basis for inferring causation. This criterion can be modified in certain circumstances by competing causes of death, "all-or-nothing" biological responses that cannot be repeated, and resonance-related phenomena such as electromagnetic radiation, in which the dose-response relationship can change depending on frequency and field strength. In environmental studies it is often possible only to achieve an ordinal scale for dose, cf. "more" or "less," rather than a more accurate, continuous scale. Note here that the use of the term response relationship is an analog of, but not the same as, its use in toxicology/pharmacology — where the response is not a population-based *risk* measurement, but rather some biological phenomena inside an organism.

Biological Plausibility of Association. The disease mechanism should be observable in animal models using the methods of laboratory disciplines (e.g. pathology, microbiology, etc.) Unfortunately, laboratory models do not exist for some human (and animal/plant) diseases. There should, however, be a plausible biological mechanism by which the exposure-effect sequence could conceivably occur.

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[1] The level of significance measures the so-called Type I error, or the likelihood of accepting an observed difference as real when it is, in fact, due to chance alone. A complementary concept is the Type II error, which measures the likelihood of rejecting an observed difference as unreal when it is, in fact, real. When the level of significance used to test an observed difference is made more stringent, the power of the test to detect a real difference is decreased. The power of a statistical test is very important when negative results, i.e. no effect is seen, are observed. The design of the study and the sample size predetermine the probability of a false negative result.

Coherence of the Relationship. This criterion broadly implies that the hazard-exposure effect should be compatible with the known distribution of both the hazard and the health outcome over space and time. Thus childhood acute lymphocytic leukemia could not be primarily caused by electromagnetic fields if that condition is most common in rural developing countries where few strong electromagnetic fields are found. Similar studies should confirm the relationship, including studies in other branches of science and bioscience, such as those showing similar exposure-effect phenomena in animals or plants in the wild. The latter are often added as an analogy of additional criterion for inferring causation.

Experimental Confirmation. Laboratory studies on animals can test the cause of relationships between hazards and human disease. This obviously requires, however, that appropriate animal models are available to test the relationship. For those hazard-exposure effect sequences without such models, it is generally unethical and infeasible to conduct experiments in which humans are randomly exposed to a possible hazard, to see if the putative effect ensues. Thus environmental epidemiology is virtually always bereft of this most potent of Hill's criteria for causation. Some observers think of the demonstration of "reversibility" of health effects, after hazard abatement, as equally good "experimental" evidence of causation. However, many health effects are simply not easily reversed, or have long latencies after hazard exposure and before full expression, so one may not be able to so readily demonstrate "reversibility" in many situations.

In practice the inference of causality provides the framework on which to base decisions on elimination of harmful biophysical effects in contained situations such as a workplace. It is widely used in occupational health and is necessary to investigate less well-defined situations in an environment or ecosystem.

Scientific information generated through the study of humans in the workplace has provided one avenue for understanding the broader impact of such agents in the environment (air, water, soil or food chain) or the biota (living plants and animals), which together form the ecosystem. However, human health studies alone have proven insufficient to protect fixed ecosystems for one or more of the following reasons:

- Some routes of nonhuman exposure do not exist for humans
- Some routes of human exposure do not exist for nonhumans. Humans are exposed to all sorts of commercial products that are biologically active
- Chemicals are likely to be more toxic to some nonhuman organisms simply due to interspecies differences in sensitivity, physiology, biochemistry and/or lifestyle
- Mechanisms of action at the ecosystem level may not have human analogues
- Any environmental pollution is likely to result in much higher exposure to some nonhuman species than to humans, since humans have access to air conditioning, and food and water imports that protect them from local environmental hazards
- Most birds and mammals have a higher metabolic rate than humans so they may receive a larger exposure or dose per unit body mass of some hazards
- Some chemicals released into the environment are designed to kill nonhuman organisms (pests) and result in nontarget toxicity
- Nonhuman organisms are highly coupled to their environments and therefore may experience severe secondary effects such as loss of food or physical habitat.

As in human disease, it is not always easy to identify and distinguish natural ecological changes from those potentially attributable to human action. A clearly defined biological end point with one or more associated environmental factors gives important evidence of causation, but by itself does not prove causation. Therefore in defining causality in ecological epidemiology both careful epidemiological research design and scientific supporting data from related fields is important.

In conclusion, the Inference of Causality is a methodology to synthesize epidemiological research on human, animal or plant populations and biochemical/physiological/microbiological knowledge of mechanisms. Thus the great value of the Inference of Causality lies in its integration of two disparate types of empirical evidence: the synthesis of multiple sorts of "basic science" evidence, and evidence from well-designed epidemiological studies. It represents careful scientific building of knowledge and leaves little uncertainty, **but only where there has been a large enough population of organisms with measurable exposure to a well-defined hazard to generate sufficient cases of ill-health effects to allow a statistically significant relative risk compared to control unexposed populations.** Unfortunately, all of these conditions fail to apply in many circumstances of health effects due to environmental hazards. And even when these conditions do apply, and the application of Hill's criteria is useful, the fact that one has waited until there is an actual human "body count" of affected individuals means that exposure to environmental hazards has obviously been allowed to go too far.

Limitations to this Approach: The Inference of Causality is used most appropriately with a single, well-defined and measured hazardous exposure, such as lead or methyl mercury, and a single biological effect, such as the neurotoxicity or Minimata disease. It begins with a null hypothesis, that the hazard does not cause the biological effect, and tests that hypothesis against observations using recognized statistical methodology, within the framework of particular epidemiological study designs (e.g. case-control or cohort).

While the research goals and experimental design are subject to choice, the Inference of Causality is generally considered value-free. It is also considered limited in its applicability. It usually does not, for example, include the study of mitigative activities, or the socio-economic consequences of such activities. However, when a full set of epidemiological studies and basic science information exists of relevance to a putative environmental hazard exposure and observed health effect, the application of Hill's criteria is invaluable for assessing this information impartially. Unfortunately, such full evidence is often missing in environmental hazard assessment, as has been noted above.

More frequently than not, epidemiological studies attempting to infer causality are inconclusive or have negative results, i.e. no adverse health effect is observed. This is often due to test design, the requirement of large samples, testing only one biological endpoint such as cancer death, or the effects of multiple toxic interactions. The human or ecosystem integrates all of the negative exposures received, and the resulting ill health may not be directly attributable to any one of the exposures taken in isolation. It is not possible for the science of inference, which deals best with single effects, to meet fully the challenges of multiple hazards, e.g. toxic chemicals such as occur in the Great Lakes basin.

Finally, as an approach to decisionmaking, the use of Hill's criteria is data-intensive and requires scientific products of a long period (often decades) of study. Thus, it is usually available for retrospective analysis, and less appropriate for new problems or other prospective decision situations.

Risk Assessment

The science of risk assessment addresses and quantifies, where possible and appropriate, hazard identification, dose-response (or exposure-response) relationships and exposure determination, which lead to risk characterization. Risk characterization is the primary scientific input into risk management, which will be discussed in the next section. These relationships are shown in Figure 1, taken from the International Joint Commissions's (IJC) Workshop on Risk Assessment, Communication and Management, held February 1-2, 1993. Ecological risk assessment is defined as a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

A risk does not exist unless: (1) the stressor has the inherent ability to cause one or more adverse effects, and (2) it co-occurs with or contacts an ecological component (i.e. organisms, populations, communities or ecosystem) long enough and at sufficient intensity to elicit the identified adverse effect. While some ecological risk assessments may provide true probabilistic estimates of both the exposures and the adverse effects, other assessments may be deterministic or even qualitative in nature. In these cases, the likelihood of adverse effects is sometimes expressed through a semiquantitative comparison with other more familiar exposures, risks and effects. Such assessments require sensitivity to important differences in the situations, for example, voluntary vs. involuntary risks.

The paradigm now used by the **U.S. Environmental Protection Agency** (U.S. EPA) for most human health risk assessment was developed by the U.S. National Academy of Sciences and published in 1983. Hazard identification is a part of the risk assessment process. Hazards to health or to ecological systems are those interactions with human products, activities or interventions at sufficient intensity to alter the functioning of human or ecological systems at some level of organization (including the cellular and molecular). Hazard identification depends on the collection of all relevant information derived from laboratory experimentation, epidemiology, toxicology and cytotoxicology, embryology, physiology, anatomy, biology and other relevant disciplines. From this hazard identification process, gaps in research can be identified and studies undertaken that would permit more confident statements to be made about the significance of the hazard.

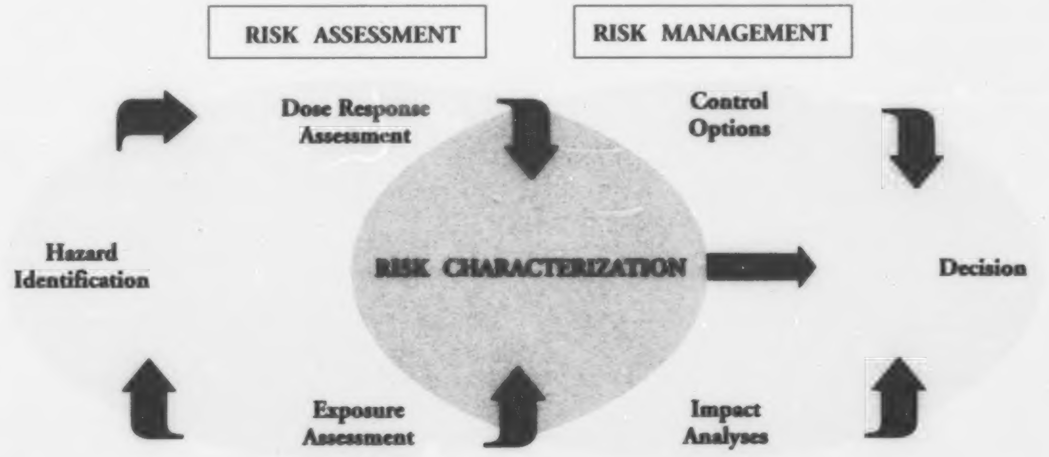

Figure 1.
Environmental Risk Characterization.
The Relationship Between Risk Assessment and Risk Management (After Farland 1993)

Hazards other than persistent bioaccumulating toxic chemicals are recognized as sources of harm to the Great Lakes Basin Ecosystem. These hazards include recreational uses of the lakes, construction and dredging operations, invasion by exotic species, and other stressors. In 1993, the U.S. National Academy of Sciences updated its 1983 report on risk assessment to include a broader definition of hazard to include those to the ecosystem as well as hazards to human health. They cited the Georges Bank Fishery Assessment as "most complete." This assessment contained a determination of the qualitative effects of fishing on fish populations. While the assessment developed in this case was incorrect, the community dynamics described are clearly analogous to the determination of contaminant effects and can legitimately be called "hazard identification." Estimates of fishing effort and models of population response to exploitation are comparable to exposure or dose-response assessments of chemicals. The expression of outcomes in terms of future population sizes and yields carries risk characterization several steps further than was done in any of the contaminant studies in the 1983 report.

The most recent developments in hazard identification are in more broadly defined "adverse effects." Ecological risk assessments do not have an equivalent to the lifetime cancer risk estimate used in most health risk assessments. The ecological risks of concern differ qualitatively between different stresses, ecosystem types and locations. The value of avoiding these risks is not nearly as obvious to the general public as is the value of avoiding exposure to established carcinogens. Because few risk managers are trained as ecologists, effective communication between risk managers, technical staff and the public is essential in sound risk management decisions. Stressors of human health are also being identified in categories other than fatal cancers, for example endocrine disruptors or chemicals causing neurotoxicity. Often it is the public, e.g. native people, hunters and mothers, who perceive hazards first and call attention to them.

The second component of the risk assessment process is the evaluation of the dose response relationships. Valid data sets should be presented with the plausible models for extrapolation from high to low dose, and from tests in laboratory species to evaluate hazards and risks in humans. In ecosystems a more generalized relationship between exposure and response must be established. Dose response has medical-human connotations, and also is more correctly applied to chemical pollution. Exposure in an ecological sense may be episodic, such as invasion by exotic species, cyclical, for example, summer recreational boating, or continuous, like the chemical runoff from agricultural land. Exposure usually has a time dimension and a magnitude or concentration dimension. These will modify the assessment of ecosystem harm. The range of hazard potency should be included in risk assessment, and general uncertainties inherent in the assessment reflected.

Response may be direct or indirect. A secondary poisoning of raptors due to accumulation of pesticide residues in their prey, or the effects of harvesting on fish community structure, would be considered indirect adverse effects. The Science Advisory Board's Subgroup on Decisionmaking in the Face of Uncertainty has identified some more subtle indirect effects which are normally understood by scientists before they become apparent to the public, and also before changes are likely to be irreversible. It is the scientist's responsibility to sound an alarm when the probability of any of these effects is in question. A stressor may be of special concern not because its characteristics pose a current risk, but because its pathways or potential host responses do, which are not immediately apparent. For example, although a chemical pollutant appears to be isolated from the biosphere in its current state, economic activities of future generations may unwittingly release it. Furthermore, adverse human reactions may occur only at sensitive points in the human life cycle, for example, the embryonic period, whereas responses are studied for the adult organism. The ecological response may be environmental collapse due to a cascade effect in the environment or food web, whereas the exposure-response examination focuses on the first link in the chain of consequences. Detailed considerations for expanding the list of indirect adverse effects of concern to society are detailed in Appendix I. These adverse effects entail further identification of stressors, detailing uncertainties, and communicating the potential harm to risk managers and decisionmakers, even if the indirect effects are difficult to predict. There is an ethical imperative to explore the long-term consequences of our activities. Social scientists must be involved more directly in the predicting of human interference and/or interruption of predicted behaviours.

The third element of the risk assessment process is exposure assessment. This aspect has taken on a large role in the past few years, in that it focuses on the populations or subpopulations that the data indicate may be particularly exposed. The potential routes of exposure from particular pathways and sources must be identified and the uncertainties and relative importance of the assumptions, exposure models and confidence in the data must be described.

It is now well recognized that exposures vary widely by habitat, niche, food web and other considerations. Humans disperse their foods globally, and exposures to toxics may occur many miles away from the point of harvesting. Species with limited range and who are locally dependent on air, water and food make good sentinels for the local ecosystem. For humans, lifestyle, hobbies and non-traditional uses of the environment also must be considered when assessing exposure. The average adult exposure may prove inadequate to describe the significant response of children or Native people. Social science can identify and quantify these factors. Exposure assessment may be influenced by temperature, acidity, humidity or other factors influencing bioavailability and/or uptake.

Exposure assessment can incorporate the physical, chemical, pharmacokinetic and metabolic data for a chemical mixture polluting an ecosystem. It must consider chemical interactions, environmental transformations (fate, transport and degradation) of complex molecules. Examining biomarkers and biomonitoring data where available and revisiting the list of "adverse effects" of public and scientific concern are all recent developments to expand and clarify this part of the risk assessment process. Biomarkers serve as indicators of exposure and help to elucidate pathways and effects.

Risk characterization is the process of combining and integrating the information and analyses derived from the three stages of risk assessment to describe the likelihood that humans or the ecosystem will experience any forms of toxicity or biophysical harm associated with the hazard. The major components of the risk are presented, along with quantitative estimates, where appropriate, to give a combined and integrated view of the evidence.

Although impact on human health is still a major focus of risk characterization, there is increased recognition that environmental sustainability is essential to human survival and an important end point for human planning. Risk characterization describes the nature and often the magnitude of risk to the ecosystem, including any uncertainties expressed in understandable terms to decisionmakers and the public. Further extension of the risk characterization definition provided in the 1983 U.S. National Academy of Science report is needed to focus on uncertainty, to facilitate expression of risks in management-relevant terms (including valuation), and to emphasize the importance of communication between scientists and managers. Risk characterization synthesizes the results of technical analyses and expresses them in a form suitable for valuation studies or other policy analyses carried out as part of risk management.

Formal analysis of uncertainty is another major subject needing improvement in ecological risk assessments of all types. The "uncertainties" discussion group at the IJC workshop in 1993 identified three general categories of uncertainty that affect all types of risk assessments:

- Measurement uncertainties, e.g. low statistical power due to insufficient observations, difficulties in making physical measurements, inappropriateness of measurements, and natural variability in organic and population response to stress

- Conditions of observation, e.g. spacio-temporal variability in climate and ecosystem structure, differences between natural and laboratory conditions, and differences between tested or observed species and species of interest for risk assessment

- Inadequacies of models, e.g. lack of or knowledge concerning underlying mechanisms, failure to consider multiple stresses and responses, extrapolation beyond the range of observations, and instability of parameter estimates.

Measurement uncertainties can be reduced by making more and better measurements. These uncertainties cannot be reduced but they can be communicated to decisionmakers and the public. It may be possible to incorporate some uncertainties in formal model uncertainty analysis, but inadequacies in the models themselves or scientific ignorance in general are much more difficult to quantify. Each of these uncertainties and associated assumptions, however, should be explained as explicitly as possible for those who must use and interpret the risk characterization conclusions.

From this discussion, and the report summarized in the IJC 1993 workshop on risk assessment, the strengths and weaknesses of this methodology for decisionmaking are clear. The strengths are: (1) risk assessment is designed to organize scientific information specifically for decisionmaking and policy purposes and is rapidly becoming reproducible in its applications; (2) because it is capable of formalizing uncertainties, it can be quantitative in those areas where other approaches are largely qualitative (i.e. where the pathways by which laboratory outcomes are observed can also be expressed in field conditions); (3) it is designed to be prospective and as broad and interdisciplinary as the problem. By design, it complements valuation studies and implementing cost-benefit studies when those are appropriate.

Some weaknesses limit the prospects for applying risk assessment: (1) its applications are generally data intensive, expensive and long-term in nature; (2) it can appear to be dissociated from risk management in the absence of full communication and transparency of the process by which judgements are reached; and (3) it can give the impression that physical and biological sciences are the sole determinants of policy, often in practice neglecting the social sciences and ethics. As in all human undertakings, risk assessment involves human values in the choice of adverse outcomes considered, numbers and types of indirect outcomes included interpretations of data used and other parameters. By making the process as clear as possible to everyone, these value judgements are more apparent to decisionmakers and to the public.

Scientific or Expert Panels

Because decisionmaking should rest on "good science," an interdisciplinary expert panel may be needed to judge the quality and appropriateness of research, mediate arguments between scientists, evaluate negative studies (i.e. those which find no association between an exposure in question and a response of concern) and generally clarify the scientific basis of certain projected findings. It is normal for scientists to disagree, and the inability of a particular research project to reject a null hypothesis is not unusual when dealing with a rare biological effect. These situations are, however, disconcerting for decisionmakers and courts.

Scientific disputes may be a stepping stone to a refined understanding of the phenomenon, to identifying new research needs, to broader recognition of conditions causing effects, or to focusing attention on previously unnoticed pathways, biological mechanisms or biophysical effects. Scientific understanding of our complex world is now expanding into non-linear models and chaos theory, a world less comforting to decisionmakers than that of predictable linear models. Yet these new models appear more realistic to the biophysical interactions of the ecosystem.

As with other methods, the use of expert panels has strengths and weaknesses. Generally, scientific panels have greater flexibility than risk assessment as a method for recognizing and accommodating information on the ecosystem impacts in a specific location. Risk assessment looks more to effects of hazards on an idealized ecosystem. The principal strength of expert panels lies in the finding's comprehensiveness and relative immediacy. Unlike either inference of causality or risk assessment, an expert panel can review all relevant information at one point in time, evaluate the uncertainty, and reach findings appropriate for the decision process. It also can identify biomonitoring appropriate to the situation and nature of the uncertainties, which could be implemented when the decision is taken to guard against untoward or unexpected effects. Thus, it can set a course "for now" with proper safeguards for subsequent review of policy and early warning of potential negative outcomes. The weaknesses of the expert panel lie in its tendency to deal with uncertainties qualitatively rather than quantitatively, and with the inherent nature of the selection process. The same findings may not be arrived at by another panel. Reproducibility is the most powerful element of the two quantitative approaches discussed previously, and although it is not lost entirely from an expert panel, it is not an inherent part of the process.

2.3.3 Risk Management

Once the scientific process, inference of causality, risk assessment or expert panel has determined the scientific basis of the decisionmaking together with uncertainties, other disciplines contribute to the decision within the constraints of the legal, social and moral systems of society. Collecting and integrating this further input into decisionmaking can be formal or informal. In Canada, it is evolving as **Risk Acceptance.** The public tolerance for risk is modified by past experience, by other risks they are currently carrying, by their knowledge, by socio-economic aspects of the problem and by the community's ethical beliefs. Some aspects of this societal input into the decisionmaking process are discussed under the headings of civic science and prudent avoidance. Both are societal attitudes brought to decisionmaking, and which colour the risks which are seen as acceptable and ethical for a particular population at this time in its history.

More formalized inputs into the assessment process, which are currently recognized in Canada, include briefs on the social equity implications of the proposal, the socio-economic impact of the proposal on culture, jobs and future plans of the community, and cumulative impact assessment which analyzes prior harm experienced by the community being asked to assume the risk, or other risks currently being carried by the community. The reality of Risk Acceptance was recognized in the U.S. when setting radiation standards for the people of the Republic of the Marshall Islands who were returning to their Atoll, contaminated earlier by nuclear testing in the Pacific. Radiation Standards more restrictive than those in the United States were used because of the prior damage the population had suffered from nuclear exposure.

While risk characterization tends to be more universal, risk management addresses a particular project or intervention at a specific time and place.

Civic Science

At the Tripartite Meeting held at the International Joint Commission's 1993 Biennial Meeting, the Great Lakes Water Quality and Science Advisory Boards, and the Council of Great Lakes Research Managers addressed the question of how to make policy decisions in the face of uncertainty, given the implications of making a decision without a proven cause and effect. Dr. Henry Regier examined the approaches used to address uncertainty in the physical sciences through the social sciences, and the transdisciplinary initiatives that are characterized by some as "new science" and "civic science." Civic science reflects the complex input from individuals in society, with their professional and disciplinary orientations, often called informed public opinion.

Central to his thesis was the need to differentiate between those uncertainties related to understanding a problem (scientific facts) and those uncertainties related to policy (what can be done about it). Resolution involves attributing the uncertainty appropriately so that methodologies and decisions can be applied within the realms of science or politics. If a scientific consensus cannot be achieved and a political decision must still be made, democratic tradition requires that a range of views be expressed by experts and the public so the decision to act may be based on societal values and ethics, rather than expert calculation (Figure 2).

The challenge of incorporating societal values within the two realms of uncertainty, scientific understanding and policy formulation, lies at the heart of the concept of civic science. This is the public domain where facts are interpreted, and societal questions emerge as part of a great iterative process systemized by governmental and educational institutions. Although science does provide a fallible but increasingly accurate description of the world, its limits are widely acknowledged by many philosophers of science. The strength of civic science occurs when there is doubt, since it derives from all of the sciences, including social sciences and ethics, the humanities and the varied experiences of members of the community. These multiple points of view enrich the dialogue (as is shown schematically in Figure 2) with professional input from the broader community, as well as their common values. Such concepts as the precautionary principle and reverse onus have arisen from communities recognizing responsibility for future generations when the consequences of actions are perceived as potentially catastrophic when the burden of proof placed on the victims of pollution has become unbearable or impossible to address within the constraints of the present system. Animals have no voice in environmental assessment hearings and human victims of pollution cannot commission a million-dollar epidemiological research project.

These strong principles in civic science are beyond the scope of the scientific risk assessment process. They imply a need for broader consultation for the decisionmaking or risk management phase of policymaking. It is important to recognize that the scientific basis of risk characterization does not dictate policy. Even when a risk is "acceptable" to scientists, it may well be unacceptable to the public. The tension between so-called "hard science" and "soft science" will no doubt help society to mature in its deliberations. Neither has a monopoly on truth.

The need for concepts such as the precautionary principle and reverse onus lies in the widespread mistrust of expert opinion, particularly when it is applied to political decisionmaking processes. While some may know everything about grammar or automobiles, there is hardly anyone who, as noted by Hoyos (1987), is "fully conversant with the present and future effects of prevailing dangers on nature and society." When experts go beyond the available data to express their opinions, they should be viewed with the same caution as would be applied to the speculations of others. In addressing future research needs to address this problem, Fischhoff et al. (1981) recommended that uncertainty be assessed by bounding it as four broad areas of knowledge:

- definition of the problem
- determination of the facts
- assessment of the human elements
- evaluating the quality of decisions that occur

Although uncertainty can be reduced through rational analysis, human judgement and decisionmaking (even by experts) becomes distorted by the tendency for people to use "rules of thumb" to simplify complex subjects. This arises from the often observed need of the human mind to rationalize and complete a thought process, i.e. if an event cannot be explained, a possible solution is invented to explain what's happened (Ingram 1994). The use of these techniques, or heuristics[2], is well established in social science research with three predominating heuristics:

- In assessing the probability of a specific event, people often resort to the heuristic procedure of availability. That is, their probability judgement is driven by thinking about previous occurrences of the event, or the ease with which they can imagine the event occurring. Research indicates that use of the availability heuristic will yield reasonable results when a person's experience and memory of observed events corresponds fairly well with the actual event being considered. It is likely to lead to underestimates if recall or imagination is difficult (e.g. there is no recent experience, concept is abstract, or it is not encoded in memory).

- Representativeness is a second heuristic procedure often used in judgements about uncertain events. In judging the likelihood that a specific object belongs to a particular class of objects, or that an event is generated by a particular process, people expect the details of the object or event to reflect the larger class or process. For example, people judge the string of coin tosses HTHTTH to be more likely than either the string HHHTTT or the string HTHTHT because they know that the *process* of coin tossing is random. While all three sequences are equally likely to occur, the first string looks more random than the other two outcomes. This phenomenon, of expecting in the small behaviour that which one knows exists in the larger set, gives rise to "belief in the law of small numbers" and is frequently used by those with formal statistical training.

- Finally, a frequently used heuristic is anchoring and adjustment. Under this heuristic, a natural starting point, or anchor, is selected as a first approximation to the value of the quantity being estimated and this value is then adjusted to reflect supplementary information. For example, when asked to estimate causes of death, respondents will produce overall lower estimates for all causes when they are given an initial reference that occurs less frequently, such as accidental electrocution (approximately 1,000 people/year in the U.S.), as opposed to a more frequent cause such as traffic accidents (approximately 50,000 people/year in the U.S.) (Morgan 1990).

In other studies contrasting expert and non-expert judgement, effects such as "motivational bias" have been noted whereby legal liability associated with professional responsibilities result in cautious, or risk averse decisions. Some examples from medical, engineering and auditing professions appear in the literature. In complex subject areas involving uncertainty, research shows that some experts have not generally performed better than their secretaries in estimating some results. While experts tend to use their knowledge of processes and actual quantitative values, the non-expert typically works backward from familiar examples and includes values that are known and that can be easily estimated. If the familiar quantities produce correct approximate values, a "best guess" can be elicited that corresponds to expert judgement.

In those areas where accurate judgements are possible, success does not depend on some unusual judgement power by practitioners. Rather, it is primarily based on the availability of a well-developed science that provides established theory, precise measurement techniques, and prespecified procedures and judgement guidelines. Thus, less reliance is placed on cognitive capacities, and the need to make large inferential leaps. When the scientific facts are known, experts do not need to rely on any intrinsic superiority in their cognitive abilities, and can simply apply their knowledge to achieve accurate judgements (Faust 1985).

In Chapter six of their book on "Uncertainty," Granger Morgan and Max Henrion conclude:

> "Although the experimental literature is not sufficiently refined to allow accurate predictions, problems appear more likely to arise in fields involving complex tasks with limited empirically

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[2] The use of heuristics was identified by the SAB in their 1989 report in terms of the use of survey research, see page 54.

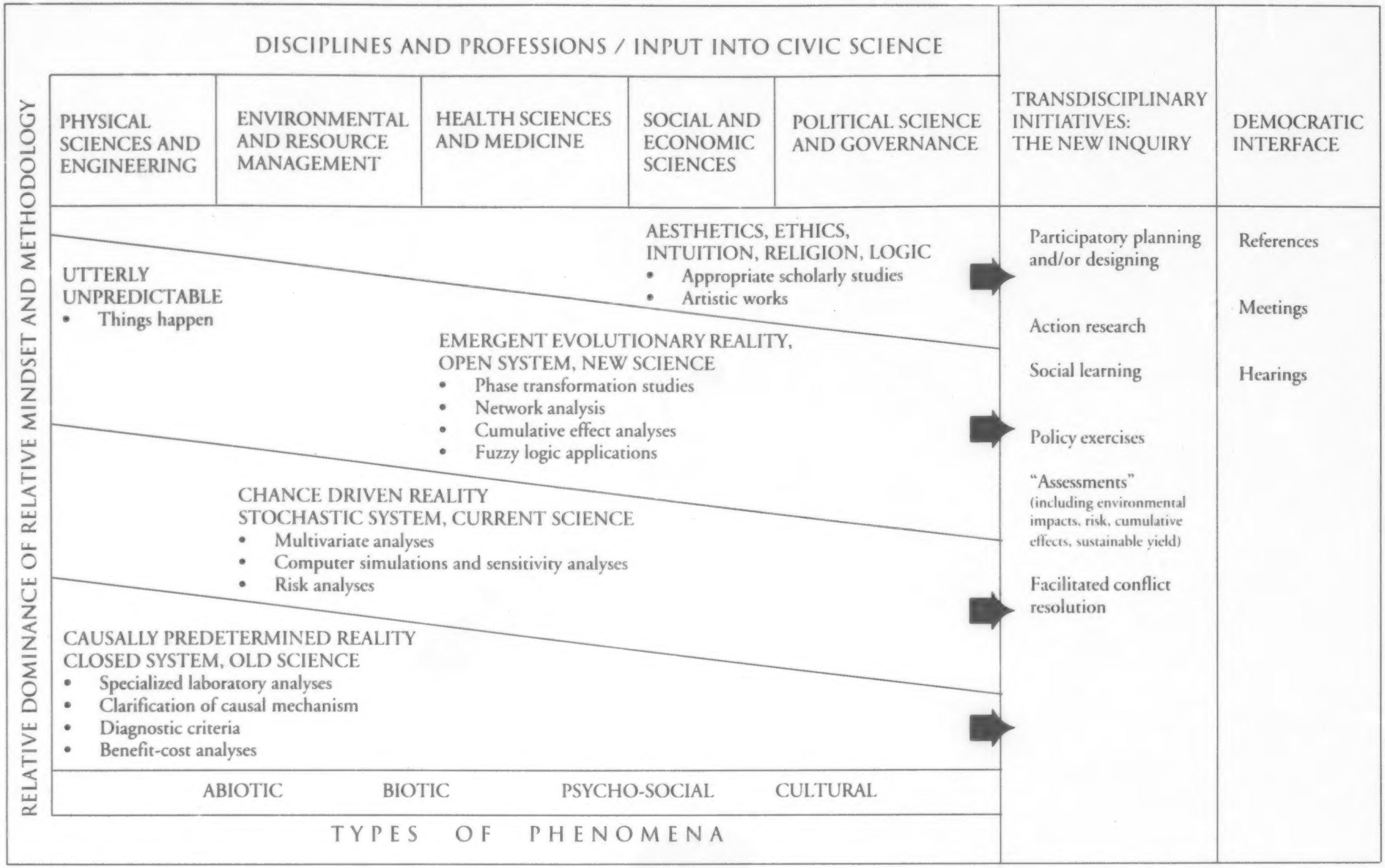
DISCIPLINES AND PROFESSIONS / INPUT INTO CIVIC SCIENCE
PHYSICAL SCIENCES AND ENGINEERING
ENVIRONMENTAL AND RESOURCE MANAGEMENT
HEALTH SCIENCES AND MEDICINE
SOCIAL AND ECONOMIC SCIENCES
POLITICAL SCIENCE AND GOVERNANCE
TRANSDISCIPLINARY INITIATIVES: THE NEW INQUIRY
DEMOCRATIC INTERFACE
RELATIVE DOMINANCE OF RELATIVE MINDSET AND METHODOLOGY
AESTHETICS, ETHICS, INTUITION, RELIGION, LOGIC
• Appropriate scholarly studies
• Artistic works
UTTERLY UNPREDICTABLE
• Things happen
EMERGENT EVOLUTIONARY REALITY, OPEN SYSTEM, NEW SCIENCE
• Phase transformation studies
• Network analysis
• Cumulative effect analyses
• Fuzzy logic applications
CHANCE DRIVEN REALITY STOCHASTIC SYSTEM, CURRENT SCIENCE
• Multivariate analyses
• Computer simulations and sensitivity analyses
• Risk analyses
CAUSALLY PREDETERMINED REALITY CLOSED SYSTEM, OLD SCIENCE
• Specialized laboratory analyses
• Clarification of causal mechanism
• Diagnostic criteria
• Benefit-cost analyses
ABIOTIC
BIOTIC
PSYCHO-SOCIAL
CULTURAL
TYPES OF PHENOMENA
Participatory planning and/or designing
Action research
Social learning
Policy exercises
"Assessments" (including environmental impacts, risk, cumulative effects, sustainable yield)
Facilitated conflict resolution
References
Meetings
Hearings

Figure 2.
Scientific and technical professionals commonly balance their work among a number of mindsets. Transdisciplinary initiatives may iterate and integrate among all types of disciplines and professions, as well as mindsets and methodologies (After: H. Regier, Managing on the way to ecosystem integrity, IJC Tripartite Meeting, October 22, 1993, Windsor, Ontario).

validated theory. There is some evidence that asking for a carefully articulated justification and reasons for and against judgements may improve the quality of judgements. . .

"The experimental evidence provides no basis for believing that the problems of cognitive bias that can arise in the elicitation of expert subjective judgement are necessarily any less serious than those that have been documented with non-expert subjects. The experiments we have reviewed clearly show the need for and importance of further studies of expert elicitation involving complex technical judgements of the sort regularly required in engineering-economic policy analysis. Until these studies are performed, one can only proceed with care, simultaneously remembering that elicited expert judgements may be seriously flawed, but are often the only game in town."

To gain a better understanding of how problems of uncertainty are addressed when judgement is applied, it is useful to consider a past problem, DDT, and a potential future problem, **recombinant bovine somatotropin** (rbST).

The case of DDT, banned in 1972, represents an early exemplar of a weight of evidence approach arising from public concern, together with scientific inquiries and hearings, which resulted in the decision to ban. The final decision taken by the Administrator of the U.S. EPA was contrary to the conclusions of a hearing, based on 9,300 pages of testimony, 300 technical documents, and 150 expert scientists over seven months. It was recommended that "no more extensive ban of DDT was necessary or desirable, based on the evidence presented at the hearings." The Administrator, however, also had to consider the outcome of state hearings and a decision by Wisconsin for immediate termination of the registration for DDT (Loucks 1971).

What methodology might be employed — given our cumulative experience and knowledge — to address the uncertainty related to the use of rbST to boost milk production in cows; a scientific issue with potential implications for human and animal health and with only a few experts available to inform the debate? A thorough analysis of the scientific literature published in *Science* magazine (Juskevich and Guyer, 1990) concluded that there was no increased health risk to consumers using a weight of evidence approach, notwithstanding that a 90-day test on a small group of rats at a given dose was the longest single test cited. Having received regulatory approval in the U.S., rbST use has now become an economic and an ethical decision to be made by farmers and consumers. Some clearly oppose rbST because they oppose biotechnology in general, while others base their conclusions on perceived risks and benefits. In the U.S., the majority of farmers are not using rbST despite the assurance of its safety by the developer, and the varied experiences reported as demonstrations (Stoneman 1995).

What conclusions can be made with respect to the foregoing?

- The concept of civic science involves more than simply public participation, and is essential to guide decision-making in a democratic society. This concept emerged from the Tripartite Meeting and the Ann Arbor workshop, "Our Community, Our Health," September 14-15, 1992, and is an emerging field for students of science and public policy. Its implications require further reflection by the Council of Great Lakes Research Managers and the Science Advisory Board.
- Experts and scientific methodologies are essential to reduce uncertainty, i.e. the negative effects of change. Ultimately, decisions are made by people constrained by knowledge, culture and values. Uncertainty can be perceived as a positive element of change embracing both innovation and opportunity, as opposed to a state of certainty which implies regression in terms of stagnation and inertia.

Precautionary Principle

How does one know that there is sufficient evidence or accumulated knowledge or potential for harm so that the reasonable person would assume scientists should sound warnings and policy makers should act?

Commissioner Gordon Durnil
"Applying the Weight of Evidence: Issues and Practice" session in Windsor, October 24, 1993

The **precautionary principle,** sometimes called prudent avoidance is an ethical imperative to prevent catastrophic damage which has a credible probability of resulting from current choice.

As was noted under risk acceptance, alarms relative to environmental deterioration raised by hunters or fishers, Native communities, mothers or others living in the Great Lakes basin are part of the "evidence" and guidance used in policy formation. Critiques by scientists who are part of the general community but who have not prepared the scientific risk assessment or been part of an expert panel may serve a special role in identifying the most worrisome characteristics, environmental pathways or ecological/human responses of potentially hazardous agents, the implications of which are not sufficiently understood by the general public or explicated by the scientific basis developed for the decision-makers. Appendix I more fully discusses the subtle aspects of hazards more easily identified by scientists, than by the general public.

It is clear from the previously discussed examples that there is potential for arbitrary use of prudent avoidance to prevent all effective decisionmaking, as well as neglect of prudent avoidance in decisions where it would be relevant. In the case of DDT, decisionmaking was contrary to the preponderance of hearing evidence and in the case of rbST the opposite happened, proceeding with a proposal without sufficient scientific support.

The precautionary principle was stated in the 1992 Rio Declaration as follows:

> "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."
>
> Principle 15, Rio Declaration, August 12, 1992
> U.N. Conference on Environment and Development

This principle requires the use of prudent avoidance when there is "sufficient evidence," "sufficient accumulated knowledge" and the risk of "sufficient potential harm." "Sufficiency" requires human judgement of the available evidence.

Because the scientific evidence and accumulated knowledge presuppose a sufficient exposed population/ecosystem and an adequate period of followup to observe long-term effects, the harm may be irreversible and unacceptable before "proof" of harm is sufficient for policymakers to act. Therefore, the third criteria is especially important because it alerts the policymaker and the public of the magnitude of the risk. Whether or not a risk is "acceptable" is a political and not a scientific decision.

The role of science in support of decisionmaking in the face of uncertain evidence is to generate theories and produce evidence that contribute to policy formation. The validity, relevance and limitations of such evidence must also be communicated.

However, democratic policy incorporates not only scientific inputs but also the ethics, aspirations, opinions and values of the society. Jack Weinberg and Joe Thornton of Greenpeace expressed the concerns of many of the people of the Great Lakes basin when they said:

> "The current condition of the Great Lakes suggests a failure in past environmental policy, a failure that was aided and abetted by limitations or failures in the science that informed that policy. It is time to re-evaluate policymaking methodologies that are based on these conceptions of "assimilable capacity" and "acceptable harm" — particularly risk assessment and risk/benefit analyses. As currently practised, these exercises never provide a meaningful prediction of real risks or real benefits. The simplified, narrow models used to "quantify" health and environmental threats bear little resemblance to the complex and unpredictable phenomena that occur when chemical mixtures enter integrated natural systems.
>
> "The societal decision to establish a particular standard of proof in some sphere of concern reflects a societal value judgement about that sphere of concern under circumstances when the data is incomplete and there is uncertainty. A policy of reverse onus protects society from the abuse of power by industry and also from corruption, arbitrary action, and even honest judgement errors.
>
> "Weighing evidence in order to decide upon a course of action under circumstances of uncertainty is not a value-neutral exercise. Precaution must be built into the rule of inference. The goal is to make inferences that can inform a course of action that will minimize the likelihood of significant harm. When the harm is large, the uncertainty is great, and our ability to predict the future is limited, we adopt a precautionary standard of judgement and inference. The use of precautionary context changes both the purpose and the practice of weighing evidence."

In order to set some criteria for identification of hazards which may potentially lead to significant harm, the Workgroup has extended the IJC criterion of persistent bioaccumulative toxic chemicals to other characteristics of hazards, namely the pathways by which they are dispersed and the nature of the human/ecological responses. These are contained in Appendix I. By so identifying the worrisome properties of potential hazards we hope to further the rational basis for policy decisions in the Great Lakes basin. When these worrisome properties are scientifically ascertainable, the ethical scientist must raise an alarm and policymakers may reasonably be expected to take some action. Minimally the response to disclosure would be:

- to **fully inform the public debate**
- to **reverse the onus of proof**, so that the burden of proving no harm must be on the polluter
- to **apply prudent avoidance** to protect the ecological/public good potentially at risk.

In an encouraging development, some industries are using their own scientific and technological resources to identify and protect against indirect negative health/ecological outcomes of human activity or products. Stewardship of the earth and good corporate citizenship are demanding responses at all levels of decisionmaking and management in our interconnected world.

The potential irreversible harm resulting from uniformed decisions about the consequences requires further development of the risk management process of decisionmaking to include explicit analysis of risk acceptance. Further developments of civic science and the policy of prudent avoidance can be expected. Management needs to consider the risk from the perspective of the actual ecosystem/human community being asked to accept the risk. Such particularization is beyond the scope of risk assessment or inference of causality, and is only partially met through the use of expert panels. Formalizing equity considerations, socio-economic impacts and cumulative impacts would go a long toward making risk management decisions transparent. For example, when such factors are not considered in planning, an already degraded area could become a sacrifice area because it is consistently chosen as the area for less desirable projects, having no "valuable assets" to lose.

2.3.4 Weight of Evidence

As outlined in the *Seventh Biennial Report*, the Commission's use of weight of evidence has been in relation to reaching conclusions and making recommendations by the Commission itself. The Commission receives input on risk assessment from inference of causality, risk assessment and scientific panels. It is also in a pivotal position to receive the input on risk acceptance both from civic science and from scientists concerned with long-term effects or more subtle indirect effects of hazards not ordinarily considered in risk assessments. As was stated in the report, the Commission takes into account "the cumulative weight of many studies that address the question of injury to living organisms."

The above description stems from recognition of the responsibilities of judges and juries to weigh the evidence and decide. In courts, expert evidence can be given a weight based on the witnesses' qualifications and credibility. The basis of a judge's choice between conflicting statements is normally stated. The phrase need not always be read and understood so narrowly, of course, and past-chairman Durnil counselled the participants at the 1993 Biennial Meeting workshop to forget the traditional legal meaning, which is the preponderance of credible evidence. Accumulating evidence means accumulating harm and tolerating processes which may become irreversible. He encouraged, instead, application of weight of evidence in the evaluation of potential for adverse effects, and suggested that the real issue was how and when do we know "there is sufficient evidence or accumulated knowledge" so that a reasonable person will conclude that policymakers should act? The *Seventh Biennial Report* notes that the decision is "made on the basis of common sense, logic and experience as well as formal science."

This brief summary of how the Commission has proposed to use the term "weight of evidence" suggests the need to resolve several issues. We need to answer the public's question: how do we proceed? One major issue is whether *assembling information*, and its weight in regard to a policy action, should all be done in one document or report. In none of the scientific assessment approaches, nor in judicial proceedings, has this been the case. Indeed, there are overwhelming precedents for the clear separation of prosecutor, judge and jury in their responsibilities for different aspects of information to be weighed. Similarly, there are many precedents for the separation of processes having to do with scientific findings (as in the three previous methodologies), and processes having to do with public policy and related decisionmaking. The questions the Commission seeks to address in its Biennial Report are, indeed, something of a hybrid among the above: The Commission is not a decisionmaking body in the usual sense, and it does not make policy (although its recommendations to the Parties can lead to policy). At the same time, the Commission is confronted with a broad range of scientific assessments and findings, often conflicting, and it sees a need for adjudicating between conflicting scientific findings. The real issue then becomes, is weight of evidence an appropriate term for such scientific adjudication? Moreover, the Commission recommendations respond not only to the risk characterization flowing from the scientific input, but also from the legal, social, economic, ethical and other inputs which are reflected in risk management decisions.

Many points of view were expressed in the October 1993 Biennial Meeting workshop, and all of the above problems were outlined. Glen Fox, of the Canadian Wildlife Service, expressed concern for applying scientific principles to determine causal explanation; Margaret Berger of the Brooklyn Law School described concern with recent U.S. Supreme Court decisions requiring the courts in general to become more sophisticated in the criteria by which they judge conflicting experts, scientific data and references from laboratory animal studies. Especially interesting is the case-study presented by William Owens, Procter and Gamble Company indicating that a weight of evidence approach (including a three-year, $3 million study) had led to successful resolution of conflicting indications of risks to fishery resources at a Canadian pulp mill. The process led to withdrawal of proposals for a potentially crippling level of proposed effluent regulation. Here, the process was designed to build consensus and resolve legitimate scientific differences as to significance, causality and interpretation. Our experience on scientific panels designed to produce recommendations for policymakers is that the transparency in the weighing and decision process is critical.

These examples, and the workshop report itself, bring us back to the basic values question posed by past-Chairman Durnil at the beginning of the workshop: How and when do we know there is sufficient evidence or knowledge that we should expect a policymaker to act? The Workshop could not answer this profoundly value-laden question, but important aspects were discussed in the paper by Jack Weinberg and Joe Thornton of Greenpeace USA. They recognize that science is a continual process of seeking truth, rather than a collection of ultimate truths, and that in the frequent absence of appropriate scientific data, risk assessments are blind — sometimes even serving as evidence of safety. They also note the continuum in weight of evidence criteria used in court: "beyond reasonable doubt" in the case of capital crimes, versus "preponderance of credible evidence" as applied to certain contracts or in administrative proceedings. Ethics and societal values are reflected in this scale of weighing, as they should be in weighing evidence for environmental risk. Thus, these authors argue for a strong precautionary standard, or reverse onus, when data are absent or sparse, and there is a potential for serious harm, rather than a weight of evidence, based on preponderance of current information, as described above.

The differences summarized here suggest the need for consensus-building in regard to societal values and tolerance of risk, in addition to methodologies for assessing the science and decisionmaking. It also calls for clarification of degree of certainty demanded of decisionmakers faced with varying degrees of threat of harm and implies the need to carefully monitor the consequences of decisionmaking when the information base is uncertain.

2.3.5 Synthesis and Findings

The approaches described in the previous sections do not exist exclusively of one another. To a great extent, they function all at the same time. To answer the questions posed at the beginning about how we should proceed, however, a goal should be that all stakeholders see for themselves how they contribute to the aggregate process. Comparisons among the approaches are useful, and can be facilitated by the summary in Table 3.

The left side of the table lists nine considerations relevant to a comparison, most of which have been discussed briefly in the preceding sections. More comparisons could be suggested. Among those shown, one of the most informative compares the kinds of information used in each of the approaches. Some approaches, such as causal explanation and risk assessment, involve intensive, long-term development of quantitative information, while civic science incorporates clearly articulated general information. Civic science incorporates general information and interdisciplinary understandings of an informed public built up over a long period of time. Causal explanation has advantages in regard to retrospective assessments, while others, such as expert panels and the precautionary principle, are more useful for problems that are arising (prospective situations). Other considerations raise questions as to the scale of the problem appropriate for each approach, inherent requirements for interdisciplinary information, documenting and reporting of uncertainty, and the different kinds of users or audiences principally concerned with each approach.

The table summary also summarizes that the finding that the cause-effect science, risk assessment and civic science are all long term, often excessively so for many of the decisions required in protecting Great Lakes water quality. To the extent that policy questions are paramount, risk assessments and expert panels can be planned, managed and designed specifically for a policy purpose, while cause-effect science is best designed for assessments used by scientific audiences. Causal relationships, when available, are incorporated into hazard identification and dose-response estimates used for risk assessment. Assessments using study groups or panels usually avoid the problems of major costs and long-term analysis, but they lack the capacity to commission critical new data, as is often required to resolve differences among studies. Findings reported by panels often reflect large uncertainties, the result not only of measurement and modelling uncertainty, but also differences among individuals in their interpretation of data. A goal of several of the approaches, including especially risk assessment and expert panels, is to make explicit: (1) the uncertainties; (2) the likely public tolerance for risk; (3) the cost to society either of not acting (and potentially incurring otherwise avoidable damage), or of acting inappropriately or too soon (and potentially incurring unnecessary harm or costs); and (4) other aspects of practical action help to inform the risk management decisions.

The three contexts for developing a risk management policy in Table 3, namely precautionary principle, civic science and weight of evidence, all must be viewed in relation to broad public interest in health, ecological integrity, resources, morality and economic wellbeing, not incorporated formally into risk management methodology, which describes the scientific base. Civic science judgements are descriptive of real-world public processes. Although they suggest that a decision or consensus is made by the public, the process is not decisionmaking in the usual sense. Rather, the policies and practices of public institutions come eventually to reflect this civic judgement. The SAB report on *Our Community, Our Health: Dialogue Between Science and Community* (IJC 1994) illustrates the process in action.

The precautionary principle probably applies best to situations where little information is available for civic science or risk assessment, but where the public agrees on a very low tolerance for the risk of future damage. The emerging public consensus that "zero discharge" should be applied as soon as possible in the Lake Superior basin illustrates a precautionary approach to protecting this ecosystem, while the efficacy of implementing similar on-land restrictions around the other Great Lakes remains part of a broader debate.

Weight of evidence, narrowly interpreted, is a shorthand term for law-related conventions guiding the judging and weighing of evidence, leading to decisions based on a broad scientific and public values evidentiary record. Thus, weight of evidence as a term describes both a process, weighing, and the decisionmaking. It also includes the context of being the endstep in the process. However, all the assessment steps, scientific as well as public, include weighing of evidence, and making personal or constituency-interest decisions based on it, but within the Great Lakes community these generalized input processes need not be blended in with the major determinations on behalf of the Water Quality Agreement, as can only be done by the Commission.

These observations or findings as to the process itself, and the end-step decisions, should be seen in relation to the different levels of proof society accepts for different kinds of judgements or decisions. We use "beyond any reasonable doubt," essentially removing uncertainty, for capital punishment decisions. But we use a simple "preponderance of credible evidence," which tolerates much uncertainty, for many administrative law decisions. Should the Commission use "beyond a doubt" for recommendations that may cost society hundred of millions of dollars in pollution abatement? Or, can such decisions (or those by scientists, or expert panels) be based on a "preponderance of credible evidence"? Conversely, is "beyond-a-doubt" evidence needed to act prudently and quickly to prevent large-scale, subtle, irreparable alteration of human health or natural resources? These choices are open, and involve critical expression of societal values that this report has sought to enlighten, but on which we make no recommendation. We simply state that the basis of the decision be made clear.

If a summary recommendation can be drawn from the information presented here, it is as follows: The weight of evidence approach outlined for policymaking in two Biennial reports of the International Joint Commission, and

Table 3.
Comparison of Assessment and Decision Approaches

ASSESSMENT CONSIDERATION	SCIENTIFIC ASSESSMENT			RISK MANAGEMENT		
	EPIDEMIOLOGICAL ASSESSMENTS (Causality)	RISK ASSESSMENT	CONSENSUS METHODS EXPERT PANELS	PRECAUTIONARY PRINCIPLE	CIVIC SCIENCE	WEIGHT OF EVIDENCE
1. Components or characteristics of the information	Time-order Consistency Coherence Specificity Strength of association Prediction of performance Plausibility	Hazard identification Exposure assessment (source strength) Dose-response (both exp. & epi.) Risk characterization	Uses panel of experts and knowledge of the science	Stated risks and public values	Values expert judgement and informed public	Available data
2. Users/ Audience	Mostly scientists	Policy/decisionmakers Bureaucrats/Politicians	Policy/decisionmakers	Public and policy/decisionmakers	Informed public/ policy and decisionmakers	Commissioners and Parties
3. Opportunities/ Disadvantages	Data intensive	Data intensive	Something we can do now	Can be rapidly implemented	Long-term consensual process	Can be done now
4. Unifactorial/ Multifactorial	Often unifactorial	Moving to multifactorial	Multifactorial	Multifactorial	Multifactorial	Multifactorial
5. Premise	Explicit formulation for identifying associations	Explicit formulation for characterizing causal factors	Consensual support	Necessity for prudence	Inclusive decisionmaking	All relevant information is weighed
6. Applicability to different scales	Tends to be universal science	Designed to be broadly understood and relevant on national and international scale	Designed to be broadly understood	Designed to include social and long-term effects	Inherently large-scale and inclusive	Flexible
7. Residual uncertainty	Minimal	Large but explicit	Large and may be explicit	Large and not explicit	Large	Large or small but it is made explicit
8. Value judgements	Design phase	Modifiers of risk factors and studies used	Panel selection/ biological endpoints	Societal values/ geographic and temporal limit	Professional and disciplinary values	Values more transparent
9. Where do you start?	Causal null hypothesis	Apparent risk identified to health or welfare	Public concern	Uncertainty over serious outcomes	Interdisciplinary	Some data available and action needed

into which many stakeholders have been invited, is too generalized and all-inclusive to function for the entire IJC community. To the extent that it refers to the Commission's own determinations, based on the full range of inputs provided biennially to the Commission, then it is an appropriate use of a well-established term. It would be consistent with prior usage if it were reserved for the Commissioners, well-documented processes. The large IJC family, who do weigh technical evidence and interpret public values, provides important input to the Commissioners' weighing of evidence, but these inputs and the processes involved should be distinguished from the final determinations by the Commission. A more satisfactory overall concept requires that two different functional elements be distinguished: scientific and public interest assessments (of all kinds) by scientists, businesses, nongovernment organizations, and the public as input; and weighing the full record and determining of policy recommendations by the Commission itself.

2.3.6 Recommendations

- **Whereas decisionmaking relative to human and ecosystem health must frequently be made on the basis of scientific and policy uncertainty, and whereas the consequences of wrong decisionmaking vary from trivial to catastrophic, and whereas a weight of evidence approach incorporates risk characterization and risk management phases of decisionmaking, the Science Advisory Board recommends that:**

  - scientific risk characterization formally include disclosure of: (1) choices embedded in the design of supporting research; (2) modifiers of risk factors used; and (3) all relevant uncertainties
  - risk characterizations prepared for environmental decisionmaking explicitly examine the potential indirect consequences resulting from the characteristics of the hazard, pathways and host response as outlined in Appendix I of this section
  - decisionmakers seek out or recommend relevant valuation assessments, legal and regulatory analysis, socio-economic assessments, equity analysis, ethical analysis and cumulative impact assessments as necessary inputs into risk management decisions.

- **Whereas the Commission recommendations of environmental policies to the Parties require broad societal understanding and support, and whereas uncertainties and potential negative outcomes of either action or non-action accompany weight of evidence decisionmaking, and whereas the priorities of human health and of ecosystem integrity may at times be in conflict, the Science Advisory Board recommends that:**

  - Commission weight-of-evidence decisions be clear as to evidence used, assumptions, values, uncertainties, and consequences involved
  - the level of proof required (beyond a reasonable doubt, or more likely than not) be clearly stated
  - the risk of non-action be included in deliberations on risk management
  - Commission recommendations and decisions based on weight of evidence include parallel decisions on reasonable monitoring needed to serve as a measure of progress toward the desired goal, or conversely as an indicator of a wrong decision
  - Commission recommendations and decisions based on weight of evidence, because tentative, incorporate clear strategies for ongoing cooperation between scientists and managers
  - further development of an ethical basis for ordering and prioritizing goals of human health and/or environmental integrity, when there is a potential conflict between those goals, be undertaken.

Appendix I.

Threats of Serious or Irreversible Damage

In order to provide clear guidelines for identifying threats of serious or irreversible damage, we have pointed out key features of the hazard, of the exposure or pathways and of the biological effects which would serve as identifying characteristics.

Justification of Use of the Precautionary Principle Based on the Toxic Chemical or Hazard Characteristics

Those features of the environmental hazard itself — such as the specific characteristics of the toxicant being evaluated in terms of its adverse effects for both the ecosystem and human health or of its presence in the environment, its kinetics in the environment and within host species, etc. — may justify prudent avoidance efforts on the part of decisionmakers before all scientific uncertainties are resolved.

Key Features of the Hazard

- **Toxicity:** the traditional definition of the hazard's ability to produce adverse effects in a host species at very low exposure doses. As a more qualitative but often critical consideration, the full span and profundity of effects must also be considered at the cellular and sub-cellular, and multi-organ-system levels that have been attributed to the hazard, often primarily in laboratory and animal studies. In other words, some environmental hazards are particularly "worrisome" not simply because they have specific health effects at very low exposure doses, but because they appear to "turn on" cellular and sub-cellular mechanisms throughout the body. Examples include some organochlorine compounds on endocrine receptors in a wide range of mammalian body cells and organ tissues, or of radionuclides at low doses which have an ability to trigger an inflammatory cascade effect. Other hazards such as invasion by exotic species or dredging of waterways may be gauged by the scale of impact as an analog to toxicity.

- **Persistence in the environment:** the tendency of the compound not to degrade to harmless substances over long periods of time, and its continued bioavailability in the sense that it is not sequestered in harmless locales, so that ongoing exposure to various biota are likely.

- **Non-remediability of environmental loading:** Related to the above, but separate, is the notion that some environmental hazards cannot be sequestered by artificial intervention or deliberate actions designed to prevent further harmful effects of their presence in the environment. On the other hand, if it is both feasible and economical to completely "seal over" a chemical contaminant (e.g. in a particular layer of lake bottom sediment) in a very local circumstance, it obviously generates much less concern.

- **Global dispersibility:** Related to the above but again somewhat separate is the capacity of some environmentally hazardous contaminants, such as PCBs or carbon 14 releases from nuclear plants, to disburse throughout the globe by virtue of specific chemical and bioaccumulation characteristics — such as their low vapour pressure, their tendency to move into food chains where some species are widely migrating, or their function as an essential chemical in all living systems. Carbon, for example, is a basic element of life and will be incorporated into organisms in both its radioactive and non-radioactive form.

- **Tendency to bio-magnify:** Again somewhat separate, but related to the above, is the notion that some compounds bioconcentrate as one sees them moving up the food chain into higher predator levels. This often has important implications for humans, who are rarely very far down the food chain, but it also has important implications for broader ecosystem effects such as "food chain effects" - cf. below.

- **Uncertain interactions with other environmental or widespread exposures:** the well-known concept of the "environmental soup of mixed contaminants of partially unknown natures and concentrations." One rarely has much information on this, but there can sometimes be basic science evidence to suggest that the interactions are likely to be biologically important and widespread.

Features of the Pathways or Exposure which call for use of the Precautionary Principle

The features of the specific exposure circumstances or pathway characteristics that lead to putative ecosystem and/or human health effects — such as the duration of exposure necessary to produce effects, the extent of deliberate versus involuntary exposure to human beings, etc. — can be important considerations in determining whether there is enough potential harm to warrant intervention on behalf of prudent avoidance.

Features of the Exposure Itself or the Pathway

- **The capacity of short-term ("one hit"/"bolus") exposure to cause significant effects:** Particularly worrisome hazards are those that appear to have the capacity to cause disproportionate adverse effects, in an individual or an ecosystem, despite very time-limited exposure, which may occur at sensitive points in the development of the individual or the species community. An example of this would be the apparent sensitivity of the rat fetus (and that of other species) to dioxin levels transmitted in utero after even one low-dose dioxin meal. In a different example, a construction project during fish spawning season might be significantly more damaging to the ecosystem than at another time because of PCBs resuspended from the sediment.

- **The widespread existence of involuntary exposure pathways that lead to the "helpless victim" phenomenon:** Exposures that are ubiquitous but poorly known to the general public are necessarily of greater concern because they prevent the individual from reducing their personal hazard voluntarily. It is therefore both a quantitative concern when the exposure is, for example, mediated through ordinary nutritious foodstuffs, as well as an ethical concern. Many contaminants fit this description, including the many pesticides that are used on fruit and vegetable crops.

- **The existence of complex multiple exposure pathways:** This characteristic of an environmental contaminant causes concern because it suggests the infeasibility of reducing overall population exposure by any simple public health or health protective measure. Again, polychlorinated biphenyls would seem to represent such an environmental hazard at the global level. Similarly tritium released to both air and water, and capable of being incorporated into the DNA molecules of all living tissue, presents a complex multiple exposure pathway.

- **The tendency for humans themselves to facilitate exposure by ongoing economic or other activities:** While some might regard this as an increased opportunity for preventive efforts, if such activities can be reduced, they raise the spectre of increasing exposure in the future when these activities expand for economic or other reasons. Thus the dredging of water channels, setting free contaminants that have previously been sequestered away from various susceptible biota, represents a potential for additional exposure and consequent harm to susceptible populations.

Significant Biological Effects Which Call For Use of the Precautionary Principle

The features of the putative or established biophysical effects that have been linked to the environmental exposure in question — such as their inherent nature, dose-response relationships, etc. — may also require action of prudent avoidance. These features also serve to define situations posing enough potential harm to warrant a deliberate decision to act or not act.

Significant Biological Effect Features in Any Population

A. Intra-Organism Effects

- **The severity, reversibility and "nastiness" of the effects themselves (including their tendency to be treated to a limited extent, or not at all):** Public policy must respond to concerns about health effects that are particularly pernicious and untreatable. Cancers of the solid tissues in children or adults is a clear example. Subtle neuro-developmental effects in children that may compromise their ability to perform as an adult, particularly their ability to perform as productive citizens and parents of the next generation, would be another example. A closely related notion not separated here is the notion of "irreversibility" of effects.

- **The presence of poorly understood non-linear/non-threshold dose-response curves:** The doses at which effects begin to occur are poorly understood for many environmental hazards, suggesting that we may have misjudged the ambient concentrations of these hazardous substances.

- **The possible presence of a dose-response relationship where there is no "no-effect" dose:** A subject of considerable controversy in the cancer literature for some decades, it is arguable that there are dose-response curves for some hazardous substances and physical phenomena that continue to show adverse effects even at micro-doses we cannot measure, so that there is no threshold below which exposure is strictly "safe."

- **Particularly "protean" or "pleiotropic" effects on organisms' functioning:** By this is meant the reduction in the capacity to perform basic metabolic or bodily defence functions, such as occurs in immunosuppression. The difficulty here is that one may misjudge mild effects of this sort because they can be signalled only through rather non-specific symptoms and signs, such as the increase in opportunistic infections, in the case of immunosuppression (witness the early days of the AIDS epidemic) - cf. below "opportunistic pathogens."

- **The bioaccumulative persistence of body burdens of the toxicant with the probability of delayed or latent effects over a lifetime:** This suggests we may only be seeing the tip of the iceberg of the effects of the exposure in short-term studies, without decades of followup in large numbers of subjects. A closely related notion is the presence of primary, secondary and tertiary "cascades" of biochemical, physiological and functional effects of hazardous exposure.

- **The extent to which reproductive or survival implications arise for the individual organism, as a result of the specific health and behavioural effects of the hazardous exposure:** In line with the considerations described below, there is more concern if the effects of the exposure in any organism compromise its reproductive success, or capability of surviving as a species.

B. Inter-Organism, Intra-Species Effects

- **Potential for population failure of whole species:** Picking up the point listed immediately above, even near-extinction of a species can often have massive cascade effects inside an ecosystem.

- **The presence of transgenerational effects:** This is mediated through a variety of mechanisms and perhaps best exemplified by mammalian species' potential to affect their offspring through germ cell and genomic changes, transplacental exposures, breastfeeding changes (in either chemical content or lactational nature), and the implications of altered parental competence to raise offspring.

C. Inter-Species/Whole Ecosystem Effects

- **Unanticipated, disproportionate cascading effects throughout a whole ecosystem:** Examples of these could be food chain effects, such as major alterations in other species' populations or densities occasioned by the disappearance of a top predator. More worrisome because of the profound "metabolic" level at which it operates inside a community of organisms, are subtle changes in nutrient cycling, such as have been demonstrated for nitrogen in polluted forests, which cause insidious nutrient "leakage" in the local ecosystem, with serious implications for its long-term sustainability.

- **The presence of "false signals" that might suggest ecosystem viability to naive observers, but in fact portend the opposite:** Examples include the overwhelming of immunodeficient species by opportunistic pathogens where the immunodeficiency itself has been caused by environmental contaminants. The tendency may be for some observers to claim that "a new germ has evolved," when in fact the pathogen that has taken advantage of the situation is merely responding to subtle changes in host defence capabilities. An example may be the current decimation by pathogens of yellow locust trees in the Appalachian region. Another example could be the explosion of certain populations, which naive observers might regard as a sign of a healthy ecosystem; for example, gulls in the Great Lakes. Exotic species population explosions may also be viewed in this way by naive observers.

A third example are situations where the inherent dose-response curve of health effects for a contaminant in the environment is "hermetic," in that small amounts of the agent appear to be necessary for health, but larger amounts cause toxicity, as with many micro-nutrients (vitamins and minerals).

2.4 TOXICOLOGICAL MECHANISMS: ENVIRONMENTAL EXPOSURE TO CHEMICALS ACTING AS ENDOCRINE MODIFIERS

2.4.1 Statement of the Problem

There is clear evidence from animal studies that many chemicals present in the environment can alter reproductive function mediated by the endocrine system. A partial list of such chemicals is shown in Table 4.

These and other chemicals have been shown in wildlife and laboratory animals to have widespread effects on the endocrine system. In fact, almost all of the endocrine organs have been shown to be affected. Effects include enlarged thyroid glands in Great Lakes fish, decreased reproductive capacity in fish-eating birds, and shortened penises and altered sexual maturation in alligators in Florida. For a more complete listing and discussion of these endocrine effects in the Great Lakes, the reader is referred to the 1992 book edited by Theo Colborn and Coralie Clement: *Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection.*

Humans accidently exposed to high levels of some of these chemicals also exhibit altered endocrine function. For example, in boys and girls accidently exposed to high levels of PCBs and PCDFs, preliminary studies (Guo et al. in press) have shown that the exposed boys have shortened penises. The boys and not the girls have decreased ability to comprehend spacial relationships, a function that is normally better developed in males than in females.

If animals exposed to these chemicals in the wild have altered endocrine/reproductive function, and if humans exposed to these chemicals at high levels have altered neuroendocrine, endocrine and sexual maturation, what if any are the effects of these chemicals on the general public? The concept that the general public may be experiencing alterations in endocrine and reproductive function, as seen in the wildlife, is very troubling. Several observations indicate that the general public may have altered endocrine function from unknown or unrecognized sources. These reports include the disputed claim that sperm counts in the adult male have fallen over the last few decades (Carlsen et al. 1992; Olsen et al. 1995; Auger et al. 1995; Sherins 1995), the observations of an increase in sperm abnormalities (Auger et al. 1995), an increase in incidence rates for

Table 4.
48 Chemicals with Widespread Distribution in the Environment Reported to Have Reproductive and Endocrine-Disrupting Effects

HERBICIDES	FUNGICIDES	INSECTICIDES	NEMATOCIDES	INDUSTRIAL CHEMICALS
2,4-D	Benomyl	β-HCH	Aldicarb	Cadmium
2,4,5-T	Hexachlorobenzene	Carbaryl	DBCP	Dioxin (2,3,7,8-TCDD)
Alachlor	Mancozeb	Chlordane		Lead
Amitrole	Maneb	Dicofol		Mercury
Atrazine	Metiram-complex	Dieldrin		PBBs
Metribuzin	Tributyl tin	DDT & metabolites		PCBs
Nitrofen	Vinclozin	Endosulfan		Pentachlorophenol
Trifluralin	Zineb	Heptachlor & H-epoxide		Penta- to nonylphenols
	Ziram	Lindane (-HCH)		Phthalates
		Malathion		Polycarbonates
		Methomyl		Styrenes
		Methoxychlor		
		Mirex		
		Oxychlordane		
		Parathion		
		Synthetic pyrethroids		
		Toxaphene		
		Transnonachlor		

Source: Colborn, T. F.S. vomSaal and A.M. Soto, 1993. Developmental Effects of Endocrine-Disrupting Chemicals in Wildlife and Humans. Environ. Health Perspectives. 101:378-384.

testicular and prostrate cancer, and an increase in the incidence of undescended testes in children. The cause of these observed changes in humans has not been identified, but the possibility exists that these effects are due to environmental exposure to chemicals.

One recent study supports the concept that environmental exposure to chemicals is having an effect on endocrine function in the general public. Koopman-Esseboom et al. (1994) studied the thyroid function of infants and mothers living in an industrialized part of the Netherlands. They found a correlation between the estimated body burdens of PCBs and dioxins and altered thyroid function in the mother and infant.

The mechanisms by which environmental exposure to chemicals exhibit endocrine effects have been studied. While there are many possible mechanisms of action, the most common mechanism may be the ability of many chemicals to act as an agonist or antagonist of the natural hormones, and binding their receptors. For example, some PCBs can act as estrogens or anti-estrogens, depending on the level of exposure to a particular PCB congener.

2.4.2 IJC-Sponsored Wingspread Symposium

In recognition of the emerging data, the complexity of the endocrine system and the potential impact that altering the endocrine system can have on other organ systems and on the incidence and manifestations of diseases, the **International Joint Commission** (IJC) sponsored a Wingspread symposium on endocrine modulators. The symposium explored the state of knowledge on the interaction between disease states and other organ systems and the endocrine system. The meeting was also designed to identify the most important studies to undertake, the sensitive parameters to be used in these studies, and the critical populations to be studied.

The topics of concern explored were the following: the effects of endocrine modifiers on endocrine sensitive cancers and cancers of the endocrine glands; immune function; neurobehavioural function; reproduction; sexual maturation development; and on the endocrine system itself. Animal and human studies were compared. Human populations were identified as useful to study for the benefit of scientific knowledge, but to benefit the subjects themselves. In addition, the potential interaction of stresses on a population and endocrine function were discussed, as well as the molecular biology of estrogen receptors.

The full report and overview of each topic area, and a summary statement of the symposium, are to be published in a special supplement to the international peer-reviewed journal, *Toxicology and Applied Pharmacology*, this fall or early winter. However, two pieces of information from the Wingspread symposium are included in this chapter. The first is the overview statement of the hormonal effects on neurobehavioural function. This overview is presented to demonstrate the complexity of the science and the many factors which must be entertained in designing the appropriate animal and human studies.

The second piece of information from the symposium is a set of research recommendations, which are supported by the Workgroup on Ecosystem Health and the Science Advisory Board.

2.4.3 Overview Statement from Wingspread Symposium, January 13-14, 1995: Hormonal Effects on Neurobehavioural Function: Priorities for Future Research

Overall, a symposium Subgroup[3] concluded that the highest priority for future work on the endocrine effects of environmental exposure to chemicals should be to develop research strategies based on more sophisticated analysis of behavioural and endocrine endpoints that might be expected to be influenced by developmental exposure to hormonally-active agents.

Much of the work to date has focused on a limited set of strongly sexually-dimorphic responses (e.g. sex behaviour and patterns of gonadotrophin release) in small animal model systems. These model systems offer significant advantages: they are standardized, involve well-characterized cellular mechanisms, and are relatively inexpensive. However, they also suffer from major drawbacks that have limited the scope and interpretation of the work. They are highly dependent on gonadal steroids (particularly estrogens) and are less sensitive to effects that may involve other hormonal mechanisms. Perhaps most important, effects on sex behaviour and gonadotrophin release in laboratory rodents cannot easily be extrapolated to higher mammals, including humans. The most commonly used endpoints of sexual differentiation in rodents — the ability to support cyclic gonadotrophin release and sex behaviour reflexes, such as lordosis — have no obvious parallels in primates. The nature and extent of the developmental risks that hormonally-active environmental agents pose for humans are thus questioned. This issue is, however, largely one of semantics. There is no question that hormonally active substances have the potential to influence human development; the challenge is to identify experimental endpoints that can give meaningful data in terms of assessing the true clinical and environmental risks of exposure to potential endocrine-active chemical pollutants.

The Subgroup considered these issues with respect to three specific areas of research: animal physiology; reproductive ecology, and human psychoneuroendocrinology.

- **Animal Physiology**

The highest priority should be to examine the effects of environmental chemical exposure using sexually-differentiated behavioural endpoints that are sensitive to changes in the integrated activity of the brain, as opposed to simple endocrine and reflex-behavioural endpoints. More complex behaviours, involving higher **central nervous system** (CNS) centers, appear to be more consistently affected by developmental hormone exposure across mammalian species than is the case with simpler reflex functions. For example, there is compelling evidence that juvenile play behaviour is sexually differentiated, with the male exhibiting more high-energy, rough-and-tumble play than females, in species as diverse as rats, rhesus monkeys, and humans. Similarly, lateralization of the brain — the preferential association of functions with either the left or right cerebral hemisphere — is affected in rodents as well as primates by early gonadal steroid exposure.

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[3] Subgroup members include Neil J. MacLusky, Ronald J. Barfield and David E. Sandberg

The Subgroup identified several types of behavioural tests that could potentially be used as more sensitive indices of possible endocrine effects of environmental exposure to chemicals:

- maternal behaviour
- preference/motivational behavioural tests of sexual differentiation, as opposed to the simpler standardized tests of male and female sex behaviour used in the majority of studies
- open-field behaviour (sensitive to both gonadal and adrenal steroid effects).
- cognitive tests using paradigms that show differences between normal males and females (particularly tests based on acquisition and use of visuospatial information)

Similar considerations apply to assessment of neuroendocrine function. The relatively "all-or-nothing" ability to support an **ovulatory luteinizing hormone**[4] (LH) surge is normally only observed in females and hence has been widely used as an endpoint for sexual differentiation, but it is an endpoint with relatively low discriminatory power with respect to the possibility of subtle disturbances of masculinization and/or defeminization. Other aspects of neuroendocrine function that are sexually differentiated and which might be expected to show more "graded" effects of environmental hormonal exposure include circadian rhythms in motor and feeding activity, which in turn are related to serum corticosteroid levels, as well as patterns of glucocorticoid secretion in response to standardized stress stimuli.

Finally, the Subgroup recognized that for all of the available test paradigms, there is a pressing need to extend previous work to analysis of more complex mixtures of chemicals, such as those present in the environment. Because of the possibility of synergism or antagonism between different compounds in the environment, laboratory data obtained on individual compounds may not be meaningful in terms of risk assessment.

- **Reproductive Ecology**

The Subgroup felt that considerable opportunities remain to obtain valuable data from field studies of reproductive fitness. Obviously greater problems exist in accurate data collection than is the case in the laboratory setting, but these are offset by the opportunity to assess the impact of "real-world" mixtures of environmental contaminants. Comparisons between the reproductive and general health of the same species living in contaminated, as compared to non-contaminated sites, could be very useful. In addition to assessments of total animal numbers and the obvious parameters of reproductive function (e.g. litter size, gonadal size, and morphology at autopsy), such studies should also include assessment of parameters that might be sensitive to subtle environmental, endocrine or metabolic effects, (e.g. sex ratios at birth and in surviving offspring, time of the onset and offset of breeding seasons, and numbers of litters per season).

- **Human Psychoneuroendocrinology**

The availability of human cohorts with defined environmental exposure provides a potentially invaluable research resource. A major problem in designing potential studies of human CNS effects of environmental chemical exposure, however, is that it is extremely difficult to eliminate potential confounding effects. Even in the case of normal sex differences, it has proven difficult to tease development hormonal responses out from the extensive contributions of social and educational factors. Testing for possible effects of endocrine active environmental contaminants on human cognitive function presents even greater challenges. It may be impossible to adequately control for the effects of differences in socio-economic background, education opportunities and biases introduced by study population expectations. Simply being aware of developmental exposure to a potentially harmful environmental chemicals may introduce confounding effects that could influence tests of human cognitive function to an even greater extent than the actual exposure to the chemicals themselves.

For this reason, attempts to detect possible effects of hormonally-active chemicals from environmental exposure on human brain development should probably be focussed on sexually dimorphic endpoints that are robust, objective and relatively easy to measure. Play behaviour in childhood is one such variable. It is normally strongly sexually differentiated, with males showing more high-energy expenditure, "rough-and-tumble" play than females. This sex difference is a consequence of developmental androgen exposure; girls with excessive prenatal androgen exposure resulting from the syndrome of congenital adrenal hyperplasia show play behaviour patterns resembling those of normal males. Therefore, environmental exposure to chemicals that interfere with sex differences in either steroid hormone secretion or action might be expected to affect play behaviour patterns.

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[4] A hormone of protein-carbohydrate composition that is obtained from the anterior lobe of the pituitary gland and that in the female stimulates the development of corpora lutea and, together with follicle-stimulating hormone, the secretion of progesterone, and in the male the development of interstitial tissue in the testis and the secretion of testosterone.

Another robust sex difference is in the extent of lateralization of brain function; males are generally considered more lateralized than females. Relatively simple, objective measures of lateralization can be achieved using methods such as dichotic listening tests. Cerebral hemispheric lateralization and other sexually-differentiated structural features of the brain (e.g. in the hypothalamus-preoptic area) could also potentially be studies using either **magnetic resonance imaging** (MRI) or at autopsy, in patients exposed to endocrine-active chemicals from environmental exposure as compared to control populations. Both approaches have demonstrated sex differences in brain structure in normal human populations and therefore could presumably be used to test for possible modulating effects of environmental chemical exposure.

Sex differences also exist in humans in the prevalence of various developmental disabilities. Mental retardation is twice as common in males as in females, while autism and other pervasive developmental disorders show a male:female sex ratio of 3-4:1. The relatively low base rates for these disorders must be considered in any epidemiological investigation of the effects of environmental toxicants. For instance, autism occurs with an incidence of 4.5-4.8/10,000 children and mental retardation ranges from one to three percent of the general population. A more common phenomenon is that of learning disabilities. These are detected in 10 to 15 percent of the school-age population and exhibit a male:female ratio of 2-5:1. Sex differences in the incidence and type of psychiatric disorder is another domain in which the potential influence of environmental toxicants could be assessed. Depression, for instance, is diagnosed twice as often in women as in men. Estrogens have been implicated in the etiology of depressions, possibly through their effects on enzymes involved in biogenic amine metabolism as well as on neurotransmitter receptor systems.

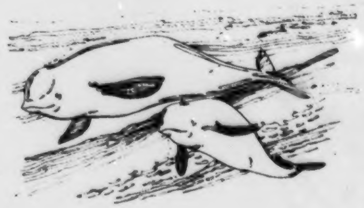
2.4.4 Conclusion and Recommendations

In animals, certain chemicals in the environment can cause a range of effects on the endocrine and endocrine responsive organ systems. An important subsequent question is to determine if these effects are observed in, or can reasonably be extrapolated to humans under environmental exposure conditions.

The Science Advisory Board recommends that:

- **cooperative efforts occur between the governments, academia, the general public and industry to focus research:**

1. to identify which, if any, environmental exposures to chemicals are or have the potential to be endocrine modulators in humans. For those chemicals identified, what are the exposure and dose-response relationships that define the potential for adverse effects?
2. to identify what effects and disease state in humans may be linked to endocrine modulation as a result of exposure to chemicals in the environment, and at what stage of development is the human most susceptible to these effects
3. to identify the mechanisms of action of environmental exposures to chemicals relative to endocrine modulation, and how such knowledge can be factored into the risk assessment process
4. to determine if structure/activity relationships can be developed to accurately predict which environmental exposures to chemicals have the potential to modulate the endocrine system
5. to determine if sensitive biomarkers of endocrine modulation can be developed and validated for use in animals and humans exposed to chemicals in the environment
6. to determine in animals if environmental exposures to chemicals that are endocrine modulators can be differentiated from other environmental stressors, such as loss of habitat, malnutrition, or changes in ecosystem dynamics that can similarly exert effects on the endocrine system
7. to determine in humans if environmental exposures to chemicals that are endocrine modulators, can be differentiated from endocrine effects that are caused by endogenous, dietary or other lifestyle stressor factors (loss of jobs, etc.). How can their interactions be studied?
8. to identify chemically-exposed cohorts that can be used to study the potential for environmental exposure to chemicals to alter endocrine function or endocrine responsive organ function
9. to identify if technologies can be devised to control the release of endocrine modulators. Can more effective technologies be developed?



2.5 FEDERAL AND PROVINCIAL/STATE TOXIC REDUCTION PROGRAMS AND RELATED ACTIVITIES IN THE GREAT LAKES BASIN: A PRELIMINARY EVALUATION

2.5.1 Introduction

The overall goal of the **Great Lakes Water Quality Agreement** (GLWQA) is to maintain and preserve the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem. To further this goal, Article II and Annex 12 oblige the Parties to reduce discharges of toxic chemicals to the Great Lakes.

In 1994, the Science Advisory Board's Workgroup on Parties Implementation investigated the status of toxic reduction programs and related activities by federal and provincial/state governments in the Great Lakes basin. It is assumed that these programs would provide some indication as to the progress being made in implementing the goals stated in the Agreement.

The Workgroup contracted with two investigators, one in Canada and one in the United States, to provide an inventory of the federal and provincial/state programs in this regard. This report is a brief synthesis of the findings of these two reports (Sadek 1994; Scheberle et al. 1994), with Workgroup member commentary. The detailed studies, including any comments received from the various agencies, are available from the Board on request.

2.5.2 Terms of Reference

In fashioning the Terms of Reference for the inventory studies, the Workgroup asked that the following questions be investigated:

- Are there laws in place requiring the collection of data and reduction in discharges pertaining to toxic chemicals?
- In addition to, or apart from, the laws identified above, are there programs in place to reduce discharges of toxic chemicals?
- In light of the laws and programs, what measurable results have been achieved and what gaps have been identified, if any?

2.5.3 Summary of Background Studies

Agency personnel in all eight Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York Ohio, Pennsylvania, and Wisconsin) and the Province of Ontario and in both federal governments were contacted in this study. A list of laws, programs and data relevant to toxic chemicals was then compiled, and an attempt was made to make this inventory as complete as possible. The inventory included information from 37 major databases in the United States and 56 in Canada. Personal interviews were conducted with 75 U.S. federal and state agency staff and 24 Ontario provincial and Canadian federal agency staff.

Two caveats about this work should be noted. First, some programs are not specifically targeted at toxics but may collect small quantities of data as an adjunct to other work. Although the Workgroup tried to include all such programs, some may have been missed unintentionally. The Workgroup, however, believes these to be a small proportion of the total effort. Second, the inventory necessarily represents a snapshot in time. Laws, programs and databases change constantly, so the findings reported below should be considered representative of conditions that prevailed in late 1994.

2.5.4 General Findings

The Workgroup found an abundance of activities of many types in both countries. Indeed, the number, diversity and incomplete cross-referencing of these programs proved a major challenge in compiling a "complete" inventory. Several general findings emerged, however, as follows:

Are there laws in place requiring the collection of data and reduction in discharges pertaining to toxic chemicals?

> All jurisdictions had laws in place to reduce discharges of toxic chemicals. Few of these laws require data collection, and few address all environmental compartments. For example, Ontario's **Municipal-Industrial Strategy for Abatement** (MISA) Program will develop regulations for municipal and industrial effluent discharges of toxic chemicals, but does not target air or solid waste emissions of those toxics. Data sets collected by statutory authority under U.S. legislation such as the **Comprehensive Environmental Response, Compensation and Liability Act** (CERCLA), the Clean Air Act, the Clean Water Act and the **Resource Conservation and Recovery Act** (RCRA) contain compliance information and therefore may be limited to certain types of substances. As a final example, the 305(b) reports required under the Clean Water Act, intended to provide a basis of comparison across a region, in fact vary considerably from state to state in terms of detail, data collection techniques, and timeliness.

In addition to, or apart from, the laws identified above, are there programs in place to reduce discharges of toxic chemicals?

Multi-media toxics reduction programs have been initiated through a number of voluntary industrial agreements. Examples of this are the federal Canadian Accelerated Reduction/Elimination of Toxics (ARET) program and individual agreements with sectors such as the Canadian Motor Vehicle Manufacturers' Association. Some voluntary programs exist in local and regional municipalities to control household hazardous wastes, and rural nonpoint source reduction activities are sponsored by a number of agricultural agencies as part of farm environmental planning. The Responsible Care program introduced in the mid-1980s by the Canadian Chemical Producers' Association is an important industry initiative directed at reduction of toxics use and emissions by member companies. The U.S. EPA's "33-50" program is another example of a voluntary initiative directed at reducing toxics.

The vast majority of data collection efforts underway in the states, provinces and federal governments, however, relates to tracking compliance of point source controls. Many toxics reduction programs have a specific media or contaminant focus and thus are difficult to compare across jurisdictions. Little effort is directed to discharges of toxic chemicals from nonpoint sources. A good example of this is the wellhead (groundwater) protection programs (see Table 5). Despite Congressional mandate, some states have taken almost ten years to submit their wellhead protection programs for U.S. EPA approval and most do not have the data from which to make determinations about nonpoint source contributions to groundwater. Additionally, recently passed House of Representatives property rights legislation is a serious blow to national wellhead protection efforts.

In light of the laws and programs, what measurable results have been achieved and what gaps have been identified, if any?

Despite the mountains of data that have been collected by the various agencies over the past ten or fifteen years, very little historical information is available on basinwide ecosystem conditions in the Great Lakes basin. Available data comprises detailed information about localized problems and conditions, but efforts to integrate these isolated databases into a regional framework are rare. The resulting data pool is fragmented, incomplete, and lacks a temporal or spatial perspective within the context of basinwide evaluation. Further complications relate to changing standards for measuring progress, including shifting benchmarks from water quality to bioaccumulative effects to resuspension/reactivation potential, and so on.

Databases may be unreliable; for example, databases such as STORET in the U.S. accept data with little internal error checking; the user may therefore have difficulty determining the quality and reliability of the data of interest. Data are often, perhaps usually, inaccessible to the general Great Lakes research community for prolonged periods because of proprietary rights and difficulties in searching and access. Some databases, such as the U.S. Toxic Release Inventory and the Canadian National Pollutant Release Inventory, may change every year as new chemicals are added to the reporting list and new facilities are required to report their emissions.

Finally, the available data have been collected for different purposes, whether to track compliance with statutory or voluntary requirements, or to assess ambient conditions in local "hot spots." It is therefore almost impossible to assess progress on a basinwide basis, as there is simply no accepted standard of comparison; there is little comparability among data sets; and the data in general lack the temporal and spatial contexts essential for such an analysis. Few agencies contacted used any formal method or criteria to evaluate the effectiveness of toxics management activities. This makes it difficult for agencies to assess the current status of programs and to establish a baseline against which future progress can be judged.

As a result of this fragmented database,

- Few agencies had sufficient data to make a comprehensive assessment of ambient water quality with respect to toxic chemicals.
- Few agencies had sufficient data to identify the relative contribution of toxic chemicals made by type of source (for example, agricultural nonpoint sources vs. industrial point sources).
- Few agencies have sufficient data to assess toxic chemical discharges or receiving water impact trends over time.

Finally, it is clear from the review that the Parties have not succeeded in developing joint or binational approaches to toxic reduction programs or data inventories. A major obstacle to a common assessment methodology is the differing legal frameworks in the two countries, which lead to different approaches to toxics management issues, different requirements for data collection, different ways that databases are used, and so on. The **State of the Lakes Ecosystem Conference** (SOLEC) provided an initial step in this direction but is still an evolving process that should be closely integrated with IJC activities and the Parties' commitments under the Great Lakes Water Quality Agreement.

2.5.5 Recommendations

It is evident that current toxic chemical management programs and data collection activities are not well coordinated between the U.S. and Canada. This situation has arisen because of a variety of factors, including differing legal frameworks and an evolving policy agenda. Nevertheless, the Workgroup concluded that current fiscal restraint initiatives make it imperative that Great Lakes jurisdictions

Table 5.
Comparison of United States/Canada Wellhead Protection Programs

UNITED STATES

States are required to complete two tables for groundwater under Section 305(b) reporting requirements. The first identifies major sources of groundwater contamination by using a qualitative ranking; the second identifies major groundwater contaminants, as well as a list of contaminants that the state monitors. Additionally, the state must submit the number of **maximum contaminant level** (MCL) exceedances for groundwater based or partial groundwater-supplied public water systems. This includes reporting the number of systems that have local wellhead protection programs in place.

The **Safe Drinking Water Act** (SDWA) has two principle purposes. First, to ensure that water from public water supplies is safe to drink. Second, to prevent the contamination of groundwater. The SDWA requires states to develop and implement wellhead protection programs that prevent contamination of the surface and subsurface area that surround wells that supply drinking water to public water systems. The 1986 amendments to the SDWA established the **Wellhead Protection Program** (WHPP). WHPP required states to designate wellhead protection areas and identify all potential manmade sources of contaminants within the wellhead area. States without approved programs receive no wellhead protection monies from the federal government, but otherwise cannot be compelled to comply.

MICHIGAN

Program	Wellhead Protection Program
Focus	Protect and ensure safe drinking water supply
Year Initiated	Approved by the U.S. EPA in 1994
Implementing Agency	Michigan Environmental Protection Agency

PENNSYLVANIA

Pennsylvania Department of Environmental Regulation submitted a Wellhead Protection Program in 1994 for U.S. EPA approval.

OHIO

Program	Wellhead Protection Program
Focus	Protect and ensure safe drinking water supply
Year Initiated	Approved by the U.S. EPA in 1992
Implementing Agency	Ohio Environmental Protection Agency

NEW YORK

Program	Wellhead Protection Program
Focus	Protect and ensure safe drinking water supply
Year Initiated	1990
Implementing Agency	New York State Department of Environmental Conservation

MINNESOTA

MPCA will be submitting a final Wellhead Protection Program in FY 1995 for U.S. EPA approval.

WISCONSIN

Program	Wisconsin Wellhead Protection Program
Focus	Protect and ensure safe drinking water supply
Year Initiated	Approved by the U.S. EPA in 1993
Implementing Agency	Wisconsin Dept. of Natural Resources

ILLINOIS

Program	Wellhead Protection Program
Focus	Protect and ensure safe drinking water supply
Year Initiated	Approved by the U.S. EPA in 1991
Implementing Agency	Illinois Environmental Protection Agency

INDIANA

Indiana will be submitting a Wellhead Protection Program to the U.S. EPA in FY 1995 for approval.

CANADA

Currently, both groundwater and surface-water protection are legislated through Section 2 of the Environmental Protection Act, which prohibits the discharge of any contaminant into the "natural environment" defined as encompassing groundwater. Although legislative structure exists to protect groundwater from contamination, federal and provincial development through both Environment Canada and the Ontario Ministry of Environment and Energy is currently at a standstill due to lack of funding, intervention and in some cases, personnel.

Implementation of the now defunct Federal Green Plan resulted in the assembly of a Federal/Provincial Groundwater Working Group, which is an ad hoc representation of federal and provincial groundwater managers that compiled responses from groundwater managers, federal and provincial departments, agencies, municipal associations and offices, and others, to identify the following main priority needs:

- The development of a National Groundwater Strategy
- The allocation of funds and human resources by water management agencies to groundwater resource managers in the context of: other resource management allocations; the economic value of groundwater; the contribution made by groundwater to surface water supplies; and the current understanding of the consequences for future generations of present-day groundwater management practices
- The protection of recharge areas; wellhead protection; and identification of potential sources

ONTARIO

In Ontario, specific regulation is conspicuously absent. The Drinking Water Unit of the Ontario Ministry of the Environment and Energy drafted a strategy for groundwater protection mechanism development, which did not receive upper management support or financial support. As a result, municipalities that rely on groundwater used for drinking purposes, have, with little assistance, been forced to devise and municipally fund their wellhead protection. Meanwhile larger municipalities that rely on surface water for drinking benefit from government programs.

Exceptions to the lack of proactive mechanisms are the rural guidelines targeting groundwater-contaminating agricultural practices developed through Agriculture Canada, and the Ontario Ministry of Agriculture, Food and Rural Affairs.

A Well Steward Project, funded by Agriculture Canada and implemented by the Ontario Soil and Crop Improvement Association has recently been devised to aid farmers financially in the protection of existing wellheads.

OTHER

Programs in the provinces of Prince Edward Island and New Brunswick share the following elements. For each well:

- the delineation of a fundamental wellhead protection area based upon the aquifer's zone of recharge, using all available data on hydrogeologic conditions
- a specific management plan to protect the wellhead
- an inventory of potentially polluting activities within the wellhead
- the identification of alternate sources of drinking water should an incident of contamination occur
- public participation and review during program development.

improve the compatibility of their laws, programs and databases with respect to the management of toxic substances. This is not to say that the Parties' programs should be identical, but rather that they need to improve their ability to compare progress on a basinwide basis. The Science Advisory Board recommends that:

- **the Commission consider toxics reduction programs as a priority for further action within the next biennial cycle. To further this priority item, the IJC should establish a special task force of the Science Advisory Board, in cooperation with the Water Quality Board and the Council of Great Lakes Research Managers, with a mandate to:**

  (a) develop standardized binational mechanisms and criteria to assess toxic chemical management laws, programs and data collection activities;
  (b) provide advice to the Commission on the design and implementation of such activities in order to assess toxics loadings to the Great Lakes basin.

- **the Commission reiterate and re-emphasize to the Parties the recommendation from the Commission's *Seventh Biennial Report on Great Lakes Water Quality*, which stated:**

  - Governments adopt a specific, coordinated binational strategy within two years with a common set of objectives and procedure for action to stop the input of persistent toxic substances into the Great Lakes environment, using the framework developed by the Virtual Elimination Task Force.

2.6 FOLLOWUP ON THE VIRTUAL ELIMINATION TASK FORCE

The issue of persistent toxic substances has remained one of the focal points for the work of the **International Joint Commission** (IJC). Since the 1970s, the Commission, with the assistance of its advisory boards, has proposed policy directions and action steps to address this problem, as demonstrated in its recommendations to the governments. One of the key recommendations in the *Seventh Biennial Report* (IJC 1994) was the endorsement of the Virtual Elimination strategy proposed by the **Virtual Elimination Task Force** (VETF), as a framework for action to implement a central policy of the Agreement.

The Workgroup on Parties Implementation addressed the role and importance of planning efforts related to implementing the proposed strategy and achieving progress toward the virtual elimination of persistent toxic substances.

The Workgroup has examined dioxin and furans as interesting examples for virtual elimination, because they raised a range of social, economic and technical issues. The Workgroup is not recommending that action proceed on any specific group of compounds. Rather, the intent is to examine the practical implications of transition to virtual elimination.

2.6.1 The Evolution of the Policy Framework for Persistent Toxic Substances

The **Great Lakes Water Quality Agreement** (GLWQA) provides the overall policy direction for toxic substances. Article II of the Agreement states that the "discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated." In addition, Annex 12 further provides direction to governments in dealing with persistent toxic substances, such as the principle that new regulatory programs must be designed in the "philosophy of zero discharge."

While the Agreement provides a framework to address persistent toxic substances, successive IJC Biennial Reports to the Governments of Canada and the United States have expanded and evolved the thinking with respect to the nature, scope and application of the Agreement goals.

Building on much of the work of the Science Advisory Board in its previous three reports to the Commission, the IJC in its *Sixth Biennial Report* provided a policy framework to address persistent toxic substances. The Commission recommended to the governments a process to further the phaseout of persistent toxic substances. The process, labelled "sunsetting," was defined by the Commission in the following way:

> "Sunsetting" is a comprehensive process to restrict, phaseout and eventually ban the manufacture, generation, use, transport, storage, discharge and disposal of a persistent toxic substance. Sunsetting may require consideration of the manufacturing processes and products associated with a chemical's production and use, as well as of the chemical itself, and realistic yet finite time frames to achieve the virtual elimination of the persistent toxic substance.

In its *Sixth Biennial Report*, the Commission recommended that specific substances be targeted for sunset (such as DDT, dieldrin, toxaphene, mirex and hexachlorobenzene). It also recommended that, in consultation with industry and other affected interests, timetables be developed to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and that the means of reducing or eliminating other uses be examined.

The sunsetting concept was further elaborated upon, and indeed, highly refined, in the report of IJC's **Virtual Elimination Task Force** (VETF), titled *A Strategy for Virtual Elimination of Persistent Toxic Substances* (1993). The VETF report traced the history of efforts to address persistent toxic substances. It noted the progression of approaches to address these substances, evolving from pollution control that manages individual substances through prevention that seek to avoid the use and generation of such substances, to environmentally-sustainable production processes. The report then developed a strategy to achieve virtual elimination, including the articulation of ten principles to guide the strategy. The premise of the strategy is that there may be a need to use specific chemicals and other raw materials, and at times, a need to evaluate whole classes of chemicals or industrial processes. The VETF proposed a use-tree analysis to assist in identifying chemical sources and where and how to intervene to more effectively address the problem. The Commission formally adopted the VETF report and endorsed its conclusions and recommendations in its *Seventh Biennial Report.*

The VETF also developed its decisionmaking process and recommended that the process be used to determine which substances should be candidates for virtual elimination, what indicators would measure progress and what approach should be taken to achieve virtual elimination.

2.6.2 Implementing the VETF Strategy — Toward Sustainable Industry

The Commission's use of the sunsetting concept, and the knowledge and elaboration added to it by the VETF, responds to the question of how, and the basis for, the identification of those substances subject to phaseout.

While there was considerable development in the policy framework on what (or if) substances should be identified for action, an equally perplexing set of issues has arisen as to how to sunset or phaseout substances once the strategy as proposed by VETF is applied. The how question, indeed, has been the growing subject of discussion and dialogue among many stakeholders. At the 1993 Biennial Meeting in Windsor, Ontario, representatives from labour, the environmental community and industry all agreed that if substances are to be phased out, the technological, social and economic issues that may arise in the implementation of such phaseout decisions must be explicitly anticipated and addressed. In effect, there was a recognition of the need to plan for the transition to cleaner production processes.

In its *Seventh Biennial Report*, the Commission recognized that an effective virtual elimination strategy would respond to the issue of how the sunset concept should be carried out in light the technological, social and economic components that might arise. Indeed, the Commission noted in its *Seventh Biennial Report* (page 29):

> Sunsetting and eliminating the many persistent toxic substances in use will take time, even with a broadly-ascribed and determined effort by all governments and industry. The scale of this effort will be massive and in some cases cause ripples throughout the economy. The continued viability of the orderly transition of the economy is also in everyone's best interest.

The Commission went on to recommend that a "consensus-building approach is essential which addresses the concerns of labour, industry, municipalities and other interests to ensure an orderly transition to an economy without persistent toxic substances." [p. 15]. Further, recommendation 20 stated that "Governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of sunsetting persistent toxic substances."

While the concept of planning is important, it is acknowledged that several of the substances on the IJC list of 11 **persistent toxic substances** (PTSs) have been taken out of commerce without the help of transition plans. The political process ultimately addresses societal transitional issues on the basis of policy, regulation and legislation. Under the market system, new technology is continually being developed and introduced that facilitates the phasing out of products and processes that are detrimental to the ecosystem. The role of planning in the context of the policy of virtual elimination of PTSs is to enhance these mechanisms for broad social change, by providing a forum for all those affected to evaluate progress, identify alternatives and agree on priorities. The successful implementation of any strategy requires planning and coordination from all sectors of society. While government is often traditionally viewed as having a leadership responsibility toward planning activities, all stakeholders share responsibilities for implementation of the strategy for PTS elimination as developed by the VETF, and for the necessary planning that it entails.

2.6.3 Workshop Sponsored by the Workgroup on Parties Implementation

To further the assigned priority, the Workgroup hosted a facilitated Workshop on Transition to Virtual Elimination on March 30-31, 1995 in Ann Arbor, Michigan. The purpose was to identify roadblocks and opportunities to achieving virtual elimination. The issue was how to plan for a transition, not if phaseout of targeted persistent toxic substances should occur. The workshop was centred around a case study using **polychlorinated dioxins** and **furans** (PCDD/F) as specific virtual elimination candidates.

Dioxin is used here as a case study for a number of advantages. Not all members of the Science Advisory Board believe it is the most important substance for action, and it is not used for that reason. It is used as a case study because the IJC has recommended action on this substances in past Biennial reports; it is a difficult substance to address since it is a byproduct. As a difficult substance, it clearly brings to light some of the important issues in the transition to virtual elimination; and there are a multitude of sources that will allow research to look at different applications of the concept to different sources.

To facilitate discussion, the Workgroup commissioned a set of papers from various stakeholder groups, including industry, environmentalists, labour and government. In the case of industry and environmentalists, each formed a consortium so that one paper from each of these constituencies could incorporate the views of a number of perspectives from that interest group.

The presenters were asked to consider the following elements in a binational perspective:

- provide a working definition of "transition planning"
- refer to existing data on loadings and sources of dioxin-like compounds from anthropogenic sources to the Great Lakes
- identify legal, economic, social and technological/scientific impediments to the elimination and "sunsetting" of these compounds
- identify stakeholders that would be economically, socially or otherwise affected by the implementation of virtual implementation strategies and need to be included in transition planning processes

- discuss mechanisms that can be used in transition planning to minimize adverse impacts, promote the maximum benefits and ensure fair and equitable distribution of the benefit and detriments of the transition among stakeholders.

The workshop also benefited from a detailed presentation on the recent U.S. EPA report, *Dioxin Re-Assessment Study* (U.S. EPA 1994) and a study on the *Quantitative Estimation of the Entry of Dioxins, Furans and Hexachlorobenzene into the Great Lakes from Airborne and Waterborne Sources* (Commoner and Cohen, 1995). As well, presentations were made on economic perspectives and green technologies. These studies are available on request. Papers were also presented from representatives of labour, environmental and industrial groups.

It is not possible to relay, even in a summary way, the wealth of information and insight of the presenters and participants of the workshop. However, a number of interesting, thought-provoking and relevant issues were raised. An inventory of issues subject to dialogue and debate, and remain so, include:

Overarching Issues
- the need not only for a transition planning process, but the need for a transition policy for North America
- the development of a suitable definition for "transition planning"

Principles for Transition Planning
- the need for clear targets and sunset mandates as a precondition to triggering of the transition process
- the need to have all relevant stakeholders involved, that is, labour, industry and communities
- the adoption of a "no net loss for workers" policy in the transition process
- a review of how to incorporate a cost/benefit analysis

Developing a "Transition Planning" Process
- develop a systematic framework for planning for orderly transition, including identifying targets and principles, establishing appropriate institutions, undertaking background research review, selecting transition mechanism and implementing the mechanisms
- apply the process to the largest contributors first (either sector or plant)

Examining Mechanisms for Transition
- the establishment of a transition fund to assist workers and communities
- examine economic, legal, voluntary and other such mechanisms to assist in the transition

The Institutional Framework for Transition
- the need for new or enhanced international, regional or local bodies to assist in the design, development and implementation plans.

2.6.4 Recommendations

There seems to be a general agreement that, in the process of sunsetting substances, planning for the transition to cleaner production processes is both necessary and advisable. Moreover, it is a concept that naturally evolves from the policy developments of the Commission. For present purposes, no specific definition of transition planning is being adopted, since no doubt the concept will evolve over time with a broader dialogue on the subject. **However, a working definition can simply be that it is a process that includes a variety of economic, legal, voluntary or other such measures intended to anticipate the transition to cleaner technologies and products by assessing the impacts to employees, communities and other affected interests. In effect it asks, what are the societal implications associated with the sunset of a substance or class of substances?** Hence, the Science Advisory Board recommends that:

- **the Commission consider planning for the transition to virtual elimination as a priority for further study and research within the next biennial cycle. Components of this research should include:**
  - a study researching a number of case histories of where there were specific efforts to facilitate the transition of an industrial sector owing to some change in circumstance (such as the downsizing of the military establishment or the phaseout of certain substances such as CFCs) to determine the lessons learned from those experiences
  - an investigation to identify the major contributors of dioxin to the Great Lakes
  - the development of a transition plan, with the participation of the important stakeholders, for the virtual elimination of dioxin inputs from one of the major contributors. The development of the plan would serve as a forum for a discussion on both the general framework and the key components of transition plans. The terms of reference of the study would include:
  1. the definition of transition planning
  2. important principles that would be included in fashioning a plan (such as who should participate in the plan design, when it is necessary, among many others)
  3. identification and feasibility of transition mechanisms (such as a transition fund) and the potential and obstacles for them to work in practice
  4. the need to establish, if at all, an institutional framework for the development, implementation and monitoring of the transition process, whether at a local, regional, national or international level.

- **the Commission sponsor one or more roundtables to engage the dialogue of stakeholders in the topic, and to further elaborate on how the term should be interpreted and applied.**

- **the Commission actively seek avenues to participate in international dialogue both within North America and beyond on transition planning.**

- **the International Joint Commission reiterate recommendation 20 in its *Seventh Biennial Report* to the governments in particular, which stated that governments, industry and labour begin devising plans to cope with economic and social dislocation that may occur as a result of initiatives designed to promote virtual elimination.**

- **Further to this recommendation, that the Commission recommend to the governments within the Great Lakes basin that:**
  - transition planning components, when deemed necessary in the sense that there is a risk of significant worker or community dislocation, be included into the specific commitments to those substances that are already candidates for phaseout, such as those identified under the Canada-Ontario Agreement (1994), and the Lake Superior Binational Program
  - governments report back to the IJC biennially on progress made in furthering these transition mechanisms.

2.7 IMPACTS OF CLIMATE CHANGE ON THE GREAT LAKES: PROGRESS TOWARDS A BINATIONAL STRATEGY

2.7.1 International Aspects

Introduction

The anticipation of climate change as a result of anthropogenic influence has been a matter of speculation in scientific literature at least since 1896 (Bolin 1994). An international assessment of its significance was initially completed in 1985, under the auspices of the **United Nations Environment Program** (UNEP) and the **World Meterological Office** (WMO) (Bolin et al. 1986). The prospect for climate change, within the broader context of global change, was addressed by the United Nations Commission on the Environment and Development (1977). This led to the formation of the **Intergovernmental Panel on Climate Change** (IPCC) in 1988 as a technical body for the scientific assessment of climate change and its first assessment report was completed in 1990. A 1992 IPCC Supplemental Report preceded the adoption of the U.N. Convention on Climate Change in May 1992 on the occasion of the U.N. Conference on Environment and Development held in Rio in that year. The ratification of this international convention resulted in the first meeting of the Conference of the Parties held in Berlin, March 31, 1995. The objective of the Framework Convention on Climate Change is "... to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, which level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." To assist the Conference of the Parties in its work, the IPCC is preparing a second assessment report to be released in early 1996. A summary report for policymakers addressing "Radiative Forcing of Climate and Review of Global and Regional Greenhouse Gas Emission Scenarios" was published in November 1994, with the complete scientific report publication planned to coincide with the Berlin Conference of the Parties.

The work of the IPCC is organized under three working groups:

- Working Group I addresses the function of the climate system, including natural and anthropogenic factors
- Working Group II assesses potential impacts, adaptation strategies and mitigation measuring, including the potential to reduce greenhouse gas emissions and the role of technology
- Working Group III focuses on economic implications, including methodologies for cost-benefit analysis, e.g. Is prevention better than adaptation? Which is the most cost effective?

The second assessment by the Intergovernmental Panel on Climate Change will include chapters with some relevance to the Laurentian Great Lakes.

Assessment

The role of the IPCC is one of assessment, similar to the role of the **International Joint Commission** (IJC) under the **Great Lakes Water Quality Agreement** (GLWQA). This assessment function is supported internationally primarily through an international framework for research on the earth's system. These programs share an institutional linkage through the **International Council of Scientific Unions** (ICSU), as well as the interpersonal involvement of some of the world's most eminent scientists. The ICSU was established in 1931 to:

- encourage international scientific activity
- facilitate coordination among the unions and national members
- design and implement international interdisciplinary scientific programs
- act as a consultant to governments and others on scientific issues that have an international dimension.

It currently comprises 23 international scientific unions, 20 interdisciplinary bodies, and national scientific members from 92 countries. The national members are typically the academics or research councils from the various countries.

Research

Earth system research is organized under four areas, all related to climate:

- the **physical climate system**, including the atmosphere, oceans, ice and snow (World Climate Research Program)
- the **interactive processes**; physical, chemical and biological, that regulate the Earth system (International Geosphere-Biosphere Program)
- the **biological diversity** of plant and animal life (DIVERSITAS[5])

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[5] DIVERSITAS; International Union of Biological Sciences (IUBS), Scientific Committee on Problems of the Environment (SCOPE), United National Educations, Scientific and Cultural Organization (UNESCO), Program on Biodiversity

- the **human dimensions** of environmental change, i.e. how human society interacts with its environment (HDP).

Within the IGBP goal to address the nature of the earth system, its past changes and uncertain future, six key questions have been identified to guide research:

- How is the chemistry of the global atmosphere regulated, and what is the role of biological processes in producing and consuming trace gases?
- How will global changes affect terrestrial ecosystems?
- How does the vegetation interact with physical processes of the hydrological cycle?
- How will changes in land use, sea level and climate alter coastal ecosystems, and what are the wider consequences?
- How do ocean biogeochemical processes influence and respond to climate change?
- What significant climatic and environmental changes occurred in the past, and what were their causes?

Other IGBP activities relevant to increasing the understanding of the chemical, physical and biological integrity of the earth include a Task Force on **Global Analysis, Interpretation and Modelling** (GAIM); a **Data and Information System** (IGBP-DIS); and a **System for Analysis, Research and Training** (START) (Williamson 1992).

The Hydrological Cycle

One IGBP core project particularly relevant to the Great Lakes is addressing how ecosystems and their components affect the water cycle, freshwater resources and partitioning of energy on earth. The hydrological cycle is a key component of the earth's climate system which links the atmosphere, oceans, land and the biosphere. Improved understanding of the hydrological cycle is essential in order to resolve uncertainties in predicting future climate change. While modelling efforts have become more dynamic and integrative since 1990, present knowledge is still largely based on the results of **General Circulation Models** (GCMs) which formed the basis of the early assessment report. Current modelling efforts seek to couple the ocean and the atmosphere (CGCMs) and have generally confirmed IPCC 1990 estimates of future warming of about 0.3°/decade (range 0.2 to 0.5°C/decade) (WMO/UNEP 1992). By accounting for the influence of the hydrological cycle, climate researchers hope to improve the certainty of predictions related to the timing, magnitude and regional patterns of climate change.

The hydrological cycle influences climate in a variety of ways. The exchanges of moisture and heat between the atmosphere and the earth's surface fundamentally affect the dynamics and thermodynamics of the climate system. In the forms of vapour, clouds, liquid, snow and ice, as well as during phase transitions, water plays opposing roles in heating and cooling the environment. Fifty percent of surface cooling results from evaporation. Water vapour in the atmosphere acts as a powerful greenhouse gas and nearly doubles the effects of greenhouse warming caused by carbon dioxide, methane and all similar gases (Chahine 1992). Clouds control climate by altering the earth's radiation budget. The release of latent heat of condensation in clouds provides 30 percent of the thermal energy that drives the earth's atmospheric circulation.

Conclusions

Other important factors related to the future prediction of climate change are determining future anthropogenic emissions of greenhouse gases and other climate-forcing agents, such as aerosols. Greenhouse gases increase the radiative effect, while aerosols reduce it by increasing the reflection of solar radiation to space. Recent studies on the effect of "dirty" clouds on climate as a result of aerosol particles mediating cover and vapour density suggest that their effect could be comparable in magnitude to the effect of greenhouse gases (Stephens 1994).

Progress since 1990 has resulted in a better appreciation of climate change uncertainties, and is driving an international research agenda aimed at their reduction. This includes (WMO/UNEP 1990):

- development of improved models, which include adequate descriptions of all components of the climate system
- improvements in the systematic observation and understanding of climate-forcing variables on a global basis, including solar irradiance and aerosols
- development of comprehensive observations of the relevant variables describing all components of the climate system, involving as required new technologies and the establishment of data sets
- better understanding of climate-related processes, particularly those associated with clouds, oceans and the carbon cycle
- improved understanding of social, technological and economic processes, especially in developing countries, that are necessary to develop more realistic scenarios of future emissions
- development of national inventories of current emissions
- more detailed knowledge of climate changes that have taken place in the past
- sustained and increased support for climate research activities which cross national and disciplinary boundaries; particular action is needed to facilitate the full involvement of developing countries
- improved international exchange of climate data.

It is not expected that the conclusions of the IPCC will change significantly in their second assessment report, to be released in early 1996. This conclusion, in part, stated that (WMO/UNEP 1990):

- Global mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the five global mean warmest years being in the 1980s. Over the same period, global sea level has increased by 10-20 cm. These increases have not been smooth with time, nor uniform over the globe

- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus, the observed increase could be largely due to this natural variability; alternatively, this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more
- There is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future, and cold episodes less frequent
- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use by vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

With the scientific certainty of rising global average temperature, including the highest year on record in 1990, the June 1991 eruption of Mount Pinatubo in the Philippines emitted large quantities of sulphate aerosols into the upper atmosphere, which reflected incoming sunlight back into space, enough to exert a cooling effect that confirms climate models. By early 1994, however, almost all the aerosols had settled out, clearing the way for a resumption of the warming trend (McCormick et al. 1995). The year 1994 brought renewed evidence of global warming with record temperatures in many countries. Recent estimates project cumulative emissions of CO_2 from energy and industry of 3-1/2 to 10 times larger in the coming century than in the past, unless significant efforts are made to reduce emissions, and confirm the IS92 emission scenarios developed as input to the GCMs for modelling future climates (Bruce, personal communication).

2.7.2 Regional Assessment of Freshwater Ecosystems and Climate Change in North America

This symposium, held in October 1994 in Leesburg, Virginia, was organized by the American Society of Limnology and Oceanography and the North American Benthological Society and sponsored by the U.S. Environmental Protection Agency and the U.S. Geological Society. Drs. Diane McKnight and Alan Covich chaired the conference. For analysis North America was divided into eight regions, one of which was the region of glacial lakes, including the Laurentian Great Lakes. Three products are expected. These are: (1) eight regional assessments of the potential effects of global climate change to be published in the journal, *Hydrological Processes,* (2) an early summary of these eight assessments, and (3) a special issue of *Limnology and Oceanography* containing the peer-reviewed papers presented at the symposium. A summary of the assessment for the region of glacial lakes is provided below:

Laurentian Great Lakes and Precambrian Shield (Magnuson et al. 1995)

> This region is water-rich with low relief, cool to cold in winter and warm to cool in summer. A multitude and diversity of lakes and associated WETLANDS and streams dominate the area. Included are the Laurentian Great Lakes, smaller glacial lakes, streams, and wetlands south of the permanent permafrost to the southern extent of the Wisconsin glaciation. Lakes are emphasized in our analysis owing to the existing breadth and intensity of lake research. Physical and biological processes and conditions of these systems are sensitive to potential climate change as are associated human values. Paleo analyses of lake sediments and time series of weather data and ice phenologies indicate that the region is warmer and wetter now than several thousand years ago. Observed air temperatures, summarized from 1911 for the Great Lakes - St Lawrence area, have been increasing at a per decade rate of about 0.11°C (spring) and 0.06°C (winter) with little change observed in summer and fall. Similarly annual precipitation has been increasing at a per decade rate of 2.1%. Ice thaw dates on selected lakes indicate that late winter temperatures have warmed by about 2.5°C since the mid-1800s. **Carbon dioxide doubling** ($2XCO_2$) scenarios from the Canadian **General Circulation Models** (GCM) generated warmer temperatures of 6-10°C (winter) and 4-5°C (summer). Scenarios for summer are dryer in western Ontario (-20%) but show little change or slight increases elsewhere. Scenarios for winter are wetter in western Ontario and northern Minnesota, Wisconsin and Michigan (+20%) but show little change or slight decreases elsewhere.
>
> Two overarching considerations shaped our thoughts: 1) the wide array of expected changes, and 2) differences in expected responses within the region. Potential changes include changes in physical limnology; hydrology in respect to water levels, weathering, and residence times; solar radiation in respect to changes in cloudiness, **dissolved organic carbon** (DOC) concentrations, and deep water oxygen concentrations; and distribution, growth, and persistence of fishes. Watershed and lake-specific factors were identified as key considerations.
>
> Various limnological models have been used to extend climate scenarios from the General Circulation Models to physical limnological scenarios. With a doubling of carbon dioxide, these models generate stream temperatures that track air temperature, summer lake temperatures that are 1 to 7°C warmed in the epilimnion and

6°C cooler to 8°C warmer in the hypolimnion, deeper or shallower thermoclines by up to 4m, sharper thermoclines, and reductions in duration of ice cover by several months, including the absence of ice cover at some latitudes. To the south, the loss of ice for some lakes in some years indicates that dimictic lakes would become monomictic and mix through the winter; summer stratification would become longer. To the north, some lakes that presently are monomictic and mix during summer would stratify in summer and become dimictic. Dimictic deep lakes would be less likely to mix completely. All of these changes would influence the lake ecosystems.

Hydrologic scenarios with a warmer and dryer climate produce lower lake water levels which should change WETLANDS, alter spawning opportunities for fishes and substrates for littoral benthos, and increase demand for water for agriculture and other uses. For Lake Michigan various $2XCO_2$ scenarios produce a decrease in water level of 1.25 to 2.5m. For the Illinois shoreline of the Chicago area, increased costs for dredging, extending water intakes, relocating beach facilities, and extending storm water outfalls have been estimated at $280 million to $540 million. Other direct economic impacts include increased costs of shipping in the Laurentian Great Lakes and reduced production of hydroelectric power at Niagara Falls.

Lower runoff under a dryer and warmer climate would affect biogeochemical processes, such as slowing the weathering of silicate rocks and decreasing solute fluxes to lakes. Conversely, concurrent increases in water residence time would cause higher solute concentrations and greater internal alkalinity generation. Lower wetland water tables could decrease the extent of reducing environments, increase acidic flows, and decrease DOC and trace metals in inflows. The decrease in DOC should increase water clarity, deepen the thermocline, increase benthic algae and invertebrates. Such logically predictable changes have been observed in the Experimental Lakes Area of western Ontario during the recent 20-year period of progressively warmer and dryer weather.

Fishes are aerobic ecotherms and would respond strongly to changes in temperature and oxygen concentrations. Generally, simulations driven by climate scenarios, both for large and small lakes, increase thermal habitat for warm water, cool water and even cold water fishes if oxygen is not depleted in deep water. Scenarios also generate increased body growth if there is sufficient food to meet the higher metabolic demands at warmer temperatures. For some more extreme scenarios and latitudes, there is an increased probability that temperatures would reach lethal levels both for cool water and warm water fishes. Simulations also suggest that deep water anoxia is more probable which could eliminate cold water fishes. Warmer groundwater and stream temperatures would cause habitat reductions and loss of some cold water and cool water fish populations.

Local lakes and streams do not necessarily exhibit coherent responses to the same climate changes and variability. Lakes integrate changes over different timescales because their water residence times as influenced by lake size and inflows differ. Specific spatial factors that alter hydrologic responses of lakes to climate changes are regional climate, geomorphic setting and substrates, mean depth, ratios of lake/drainage area, and lake volume/total basin storage. Differing hydrologic responses can interact with differences in ecosystem structure and function. The reduction in ice cover can decrease winterkill of fishes in a shallow forest lake, but increase winter mortality of whitefish eggs in bays of the Laurentian Great Lakes. This results not only from the physical differences between tiny lakes and great lakes, but also from differences between their species in life history and physiology.

Five broad research needs were identified:

- Long-term research and monitoring be maintained and expanded at key locations
- Models of aquatic system behaviour be improved and tested against long-term data and manipulative field experiments
- Climate models be improved to include outputs of wind and clouds and at temporal and spatial scales more suitable for subregional analyses
- Heterogeneity of potential responses should be recognized and a predictive understanding of this heterogeneity be developed
- Laboratory studies on the response of fishes to altered temperature regimes.

2.7.3 Binational Approach for the Great Lakes

The **Great Lakes - St. Lawrence Basin** (GLSLB) Project on "Adapting to the impacts of climate change and variability" is an integrated climate impact assessment lead by the Atmospheric Environment Service of Environment Canada (Mortsch 1994). The project objectives are to determine the impacts of climate variability and change in four theme areas: water management, land use and management, ecosystem health and human health, and to demonstrate how activities can develop adaptation strategies to reduce vulnerability.

Several study concepts were developed during two 1993 consultation workshops, cosponsored by **l'Association de climatologie du Quebec** (ACLIQ), Health Canada and Environment Canada in Quebec City and Montreal (Mortsch et al. 1993; ACLIQ 1993). Eight collaborative research projects are presently in various stages of completion (Mortsch 1994).

A Global Climate Change Workshop was convened on December 6-8, 1993 in Ypsilanti, Michigan, by **National Oceanic and Atmospheric Administration's** (NOAA) **Great Lakes Environmental Research Laboratory** (GLERL), the **Cooperative Institute for Limnology and Ecosystems Research** (CILER) and the Great Lakes Commission. The Administrator of NOAA had charged GLERL with developing the United States component of a binational Great Lakes global climate change study. The objective of the workshop was to link the study with the ongoing initiative coordinated by the Canadian Atmospheric Environment Service. Thus, the workshop agenda included:

- assess the current status of global change research and impact assessment in the Great Lakes
- identify unmet needs in these areas
- develop a United States Great Lakes Climate Change Research Plan to address these unmet needs and lay the foundation for basinwide adaptive strategies.

The workshop (Ryan et al. 1994) included nine formal presentations and five breakout discussion groups focussing on issues related to: economic/social assessment and impacts; ecosystem and public health; landscape/long-term measurements; physical/climate systems; and water policy and management.

The main conclusions and recommendations can be summarized as follows: potential effects of climate change and variability could have several consequences for the economic, environmental and social fabric of the Great Lakes basin, such that:

- a study should be undertaken to investigate the potential impacts of climate change and adaptive and mitigative strategies to address the potential consequences
- the proceedings of the workshop should be used as a basis for a United States Plan of Study.

A Canada-U.S. committee met fall of 1994 and spring 1995 to plan a binational symposium to be held in 1996, and to develop a Binational Implementation Plan as a terms of reference for the Great Lakes - St. Lawrence Basin Climate Change Project.

The Board notes that NOAA's participation in this project responds to its recommendation from its 1993 report that the "Parties develop and implement a binational program to address global climate change through the integrated study of the Great Lakes basin as a regional pilot project." Such an approach, lead by NOAA and Environment Canada, and involving state and provincial agencies epitomizes the benefits that can occur when bination-al cooperation and scientific consensus are achieved on an important issue.

Research Objectives and Framework

The goal of the Binational Implementation Plan is to undertake research that will improve understanding of the complex interaction between climate change and variability, the environment, and our social and economic systems so that informed regional adaptation responses can be developed for the regional sustainable management.

To achieve this goal, the research agenda is directed to achieve the following objectives:

- develop indicators of climate change to identify sensitivities and thresholds
- identify in a measured, quantitative way, how activities and systems respond and adapt to direct/indirect impacts of climate change and variability
- identify and evaluate adaptation strategies
- "integrate" (link and coordinate) biophysical and socio-economic impact assessments and potential adaptation responses
- communicate impact and adaptation results to targeted decisionmakers and affected groups as well as the public and scientific community.

These objectives will be addressed through a comprehensive research program combining scientific and policy concerns, according to a framework comprising themes and crosscutting topics.

Four specific climate-sensitive theme areas were identified and five cross-cutting research topics were developed to focus and integrate the binational research agenda. The research framework is a matrix (Figure 3) which links the theme areas with the range of research topics that should be incorporated into studies associated with the project. The matrix also indicates that the climate-sensitive issues are integrated and linked and that impacts and adaptation strategies in these areas affect each other.

In particular, a major research project proposed by the Great Lakes Commission will strengthen understanding of climate-human interactions and in so doing, identify policies and management procedures to promote human adaptation to climate fluctuations and the development of a Great Lakes Water Resources Management Program. The latter is a policy framework to establish a process by which government jurisdictions in the Great Lakes basin can anticipate and adapt to the impacts of climate change

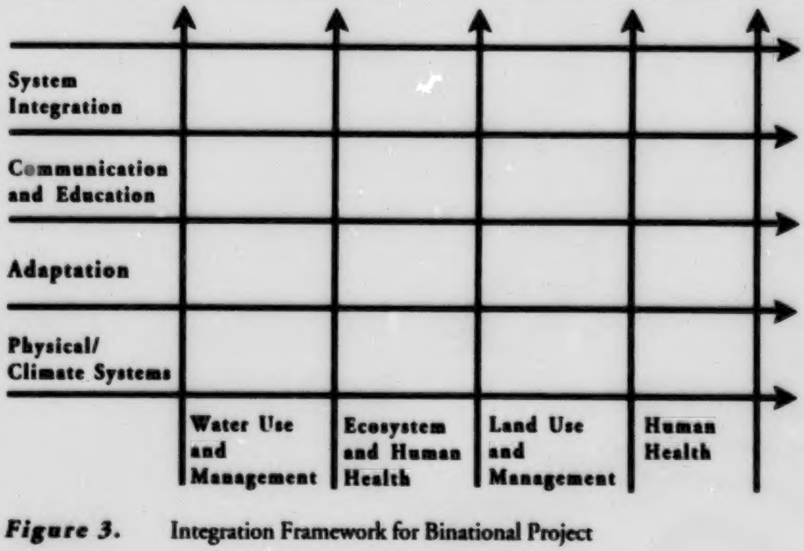

Figure 3. Integration Framework for Binational Project

through the informed use, development and protection of their shared water resources.

Research Opportunities

The research framework is flexible and comprehensive and provides a basis for further research initiatives to add to the knowledge base of the binational project as opportunities arise. Specific study areas that would benefit from additional research include:

- assessment of the human health impacts of climate change
- impact of climate variability and change on Areas of Concern and implementation of remedial efforts
- impact of climate variability and change on groundwater, ecosystem processes, wetlands, biodiversity, lake circulation and water quality
- impact of changing agroclimatic conditions on agricultural practices
- impact of climate change on long-range transport and atmospheric loadings of toxics.

Much of the current climate impact assessment research has focused on the southern portion of the basin, while Lakes Superior and Huron, the St. Lawrence River, and inland waterbodies have received less research.

2.7.4 Conclusions and Recommendations

The Science Advisory Board congratulates the Parties for developing a comprehensive and integrated research program that addresses many of the major issues concerning climate change relevant to the Great Lakes. It is noted that a *symposium is planned for 1996, as a followup to the* binational meeting initially held in Chicago in 1988. This symposium will provide a major opportunity for researchers to discuss and incorporate current global and regional efforts in order to develop the 1988 proposal for an integrated study of the Great Lakes basin as a regional pilot project for an international response to global climate change. This recommendation was recently reiterated by the IJC in their *Seventh Biennial Report.*

The proposed Binational Implementation Plan develops such an integrated study, providing it receives the Parties' support through to its completion in 2001. Accordingly, the Science Advisory Board recommends that:

- **the Parties be encouraged to support the completion of the binational implementation plan through to 2001 according to the scheduled timeline as indicated in Table 6.**
- **a quinquennial symposium on climate change in the Great Lakes basin be sponsored by the Parties and sustained following the event planned for 1996, as an important scientific forum for discussion and to measure progress towards climate change assessment and adaptation.**
- **the recommendation from the 1993 Science Advisory Board report, that the Parties make a long-term commitment to climate change research under Annex 17 of the Great Lakes Water Quality Agreement, and report progress in a holistic and systematic fashion within the context of a State of the Great Lakes Basin Ecosystem report, receive further consideration and emphasis in the IJC recommendations to the Parties.**

PHASE	1995	1996	1997	1998	1999	2000	2001
Phase 1	▨	▨	▨				
Activities (current)	C, W, L, H, E, SE, A, S	W, C, E, SE, A	W, C, L, H				
Phase 2		▨	▨	▨	▨	▨	
Activities (GL2000 & binational funding)		RAPS Wetlands Watershed trends Air toxics NA3E* S Socio-economics					
Phase 3			▨	▨	▨	▨	▨
Activities (Binational policy issue - water management			Background papers S Gaming exercise Water management/ diversion scenarios				
Milestones	• Canadian progress report Binational scenarios report	• Binational symposium	• Phase 1 report individual study reports/papers	• Stakeholder evaluation		• Phase 2 report individual study reports/papers	• Binational symposium Final report

RESEARCH TOPIC				CLIMATE-SENSITIVE THEME			
S	System integration	A	Adaptation	W	Water-use and management	L	Land use and management
CE	Communication and education	SE	Socio-economic impacts	E	Ecosystem health	H	Human health
		C	Climate and physical systems				

Table 6. Timeline of Great Lakes-St. Lawrence Basin Project Activities

* NA3E = North American Environmental, Economy and Energy Model.

2.8 IDENTIFICATION AND ASSESSMENT OF EMERGING ISSUES

2.8.1 Introduction

The Workgroup on Emerging Issues conducted an inquiry and analysis of potential emerging issues, both within the Great Lakes region and more widely from sources around the globe. The goal was to identify issues that were important to the **Great Lakes Water Quality Agreement** (GLWQA), but that were not yet explicitly developed or being addressed. The results are presented here to provide material for thought and discussion, as well as provide a basis for proposals for the priority-setting process of the International Joint Commission.

2.8.2 Survey Within the Great Lakes Region

This study was directed by the Workgroup on Emerging Issues during the spring and summer of 1994. The three-stage process and its findings are presented more briefly below:

- A survey of members of the Water Quality Board, the Science Advisory Board and the Council of Great Lakes Research Managers was undertaken to identify issues, to indicate their importance, and to provide recommendations on how they should be addressed. The initial list of 31 topics from the respondents was evaluated in terms of the perception of each topic as emerging and whether it was already being addressed by current research efforts. Eleven topics were retained for followup by the Workgroup.

- All original respondents were sent a subset of eleven items and asked to rate each as high, medium or low priority as an emerging issue. Responses were ranked by two methodologies: on the basis of the consensus of respondents rating each topic high, medium or low; and by overall scoring. The two approaches yielded slightly different results, and were generated to test different analytical approaches, rather than to provide a comparative assessment.
    - Approach 1. This approach accommodated minority views when a topic was rated by some respondents as high, and others as medium or, by some as medium, and others as low. No single issue fell into all three categories.
        - *High group* had the highest of rating from all respondents
        - *High/medium group* were rated by respondents as either high or medium
        - *Medium/low group* were rated by respondents as either medium or low
    - Approach 2. Assigned scores of: high = 3, medium = 2, and low = 1, were summed to give a total score from all respondents (Table 6).

- Each topic was then assessed in terms of the current research effort determined by the 1991/92 Research Inventory by the Council of Great Lakes Research Managers (included on Table 7). The Workgroup understood the inventory's limitations acknowledged in this report and viewed the research categories as broadly indicative of the level of effort associated with each category. No attempt was made to relate specific research projects within the categories to the emerging issues. Topics identified as receiving significant funding are related to toxic chemicals, exotic organisms, the ecosystem approach and human health. These results indicate that respondents had a difficult time separating important items for the Great Lakes from emerging items for the Great Lakes. An important item was posited to be one that was highly rated and also received significant research funding, while an emerging item was rated high to medium and even as low, but received little or no research funding.

Conclusions

This assessment identified several possible emerging issues, i.e. items that were judged to be important at some level but which have received little or no attention based on the level of research funding identified in the Great Lakes Research Inventory (IJC 1993). The issue of sustainable development was clearly evident as an emerging issue warranting further study. In summary, the emerging issues were:

1. sustainable development
2. stability of water levels
3. uv-B effects on biota
4. various implications of the **North American Free Trade Agreement** (NAFTA)
5. lifestyle choices as a factor in ecosystem integrity
6. incidence of endometriosis in women who eat fish from the Great Lakes

Table 7.
Emerging Issues: Survey Results and Current Research Effort Based on 1991/1992 Council of Great Lakes Research Managers (CGLRM) Research Inventory

APPROACH 2. Rank based on overall score		APPROACH 1. Rank based on consensus rating			CURRENT RESEARCH EFFORT based on 1991/1992 CGLRM Research Inventory (IJC 1993)		
		High	High & Medium	Medium & Low	Number of Projects	Funding ($M/U.S.)	Reference/Comments (see report for figures/tables)
1	How do we measure sustainable development for the Great Lakes?	5	1	1	Not reported as a research activity		
2	Persistent toxics from diffuse sources	1	2	10	78	10.3	Figure 3, atmosphere and Table 7, secondary source
3	Continuing introduction of non-native species of aquatic wildlife, agriculture	3	3	8	181	12.0	Table 3
4	How to implement an ecosystem approach	2	4	9	200	16.0	Figure 10
5	Long-range transport of persistent toxic chemicals deposited in the Great Lakes basin	4	4	10	47	8.5	Table 9
6	Lifestyle choices as a factor in ecosystem integrity	6	9	5	18	1.0	Figure 10. Socio-economic component
7	Incidence of endometriosis in women who eat fish from the Great Lakes	7	8	9	23	3.3	Table 8. Total research effort on health effects; specific research not reported
8	Effects of uv-B on biota	10	6	3	<12	.1	Estimated
9	NAFTA. Implications to the IJC, trade and environment, Agenda 21, biodiversity, climate	8	6	5	Not reported as a research activity		
10	Does NAFTA allow water to be a commodity and thus "traded"?	9	6	3	Not reported as a research activity		
11	Stability of water levels in the Great Lakes	11	11	2	5	0.2	Figure 11

2.8.3 Global Survey of Priorities Beyond the Great Lakes Region

Introduction

This survey reviewed general goals or future issues in policy documents from around the globe that might be relevant to emerging issues for the Laurentian Great Lakes. Information was obtained from various international and national boards, commissions, organizations or institutes and the documents were reviewed and assessed. The approach was indicative, rather than comprehensive, however it did generate ideas and increase Workgroup awareness of issues that may be important to the International Joint Commission.

Findings

Issues, especially those identified by international organizations are often broader than those under the GLWQA or the binational research and program agendas of the Parties. At the national level, priorities are more defined and provide ideas for consideration. Collectively, global issues and priorities provide a useful context for ideas on emerging issues in the Laurentian Great Lakes.

The goals of the organization or issues identified in the documents are tabulated briefly in Table 8. As might be expected many issues are identified, while others are contained at lower levels in the hierarchy in the names or acronyms of further goal-setting or issue-oriented documents.

Three organizations are cited sources of information available in further detail as an indication of priorities, goals and issues:

- The **Scientific Committee on Problems in the Environment** (SCOPE) within the International Council of Scientific Unions

SCOPE 1993 includes projects that are either underway or in preparatory phases in the current program. Projects are proposed by member nations or international organizations and are approved and launched by decision of the General Assembly. The present program is in five clusters:

- Sustainability is a broad, new subject area that includes major interdisciplinary efforts to utilize ecological and socio-economic knowledge needed to identify options for ensuring sustainability of the biosphere. Sustainability overlaps widely with all four of the other clusters.

- Biogeochemical cycles concentrates on essential elements and toxic substances, including radionucleotides. Examples are: phosphorus cycles and its interaction with other element cycles in terrestrial and aquatic ecosystems; groundwater contamination; particle flux in the oceans; nitrogen transport and transformation; and radiation from nuclear test explosions.

- Global changes assesses effects of various systemic or cumulative global environment changes in liaison with the **International Geophysical Biological Program** (IGBP), which implements research programs. Two research projects of note are: effects of increased uv-B on biological systems and effects of human activity on surficial earth processes; and the sustainability of land uses.

- Ecosystems and biodiversity focuses on ecosystem processes affected by environmental change and on losses in biological diversity, especially in relation to ecosystem functions. There are five projects: organic matter budgets; climate change in coniferous forests and grasslands; ecotones in a changing environment; the ecosystem function of biodiversity; and the dynamics of mixed tree/grass systems.

- Health and ecotoxicology develops methodologies to assess chemical risks to humans and other organisms, as well as case studies of environmental contamination. There are three projects: methods for assessing the effects of chemicals on ecosystems; methods and risk assessment for neurobehavioural toxicology; and mercury cycling in ecosystems.

- World Health Organizations **Global Environmental Monitoring System** (GEMS)

GEMS designs and develops global water-quality monitoring, relying on the following priorities:

- drinking water quality
- recreational water quality
- eutrophication
- microbiological pollution
- urban water management

Table 9 provides a list of general major water-quality issues on a global scale as developed by GEMS.

- The **World Conservation Union** (IUCN) joint report with the **United Nations Environmental Program** (UNEP) and the **World Wildlife Fund** for Nature (WWF)

The IUCN (IUCN/UNEP/WWF 1991) provides a strategy for sustainable living. Their priorities for the sustainable use of fresh waters are as follows:

- improve information and training
- improve awareness of how the water cycle works in respect to land use
- wetlands and other ecosystem units
- manage water demand for effective and fair allocation
- integrate water and land management
- increase international cooperation on water issues
- improve the institutional and community capabilities to manage and use fresh waters in a sustainable manner
- conserve the diversity of aquatic species and genetics stock

Table 8.
Science Advisory Board's Workgroup on Emerging Issues: Summary of International Responses

	AGENCY	PRIORITIES	PROCESS	ACTION
1.	United Nations	• Framework convention on climate change	• Governments to report on greenhouse gas emissions; reduction targets	• Evaluation of progress at regular meetings
		• Convention on biological diversity	• Plan development for protection of biological resources	• Canada: preparation of a biodiversity strategy by November 1994
		• Agenda 21	• Guide on environment and economy linkages in decisionmaking at national and local levels	• Local strategies on sustainable development • Canada 1994: national progress reports
		• Rio declaration	• International ethic on environment and development	• 27 principles
		• Forest principles	• Attempt to negotiate a convention on forestry	• Reconciliation of exploitation and protection of resources based on financial agreements between developed and developing countries
		• Proposed International Environmental Agency, and International Court of the Environment	• Promote international system for governance of global environmental issues	• Institutional mechanism to implement Agenda 21
2.	Institute of Freshwater Ecology. National Environment Research Council, U.K.	• Fisheries management • Physico-chemical process • Ecosystem processes • Ecosystem models	• Government research program • Provide sector contracts	• Published result of scientific studies
3.	Greek Ecologists Association	• Wetlands conservation	• Published reports of members	• Dissemination of knowledge
4.	WRC Group	• Private consultant to water utilities on quality and development issues	• Commissioned studies related to pollution control and monitoring	• Advisory
5.	Water and Environment Research Institute, Finland	• Climate change; biogeochemical cycle • Nonpoint: agriculture and forestry	• Research and monitoring programs comprising 180 projects	• Advisory
6.	Scientific Committee on Problems of the Environment; International Council of Scientific Unions	• Sustainability • Biogeochemical cycles (phosphorus, groundwater, nitrogen) • Global change (uv-B, land-use) • Ecosystems and biodiversity • Health and ecotoxicology (methods for assessment, risk, mercury cycling)	• Scientific assessment, expert meetings	• Advisory

Table 8, continued.
Science Advisory Board's Workgroup on Emerging Issues: Summary of International Responses

	AGENCY	PRIORITIES	PROCESS	ACTION
7.	International Geosphere-Biosphere Program; International Council of Scientific Unions	• Biospheric aspects of the hydrologic cycle • Global change and terrestrial ecosystems • Joint global ocean flux study • Land-ocean interactions in the coastal zone • Land-use/cover change • Post global change • Global analysis, interpretation and modelling • Data and information system • System for analysis, research and training	• Scientific assessment, academic research • Six key questions: - How is the chemistry of the global atmosphere regulated, and what is the role of biological processes in producing and consuming trace gases? - How will global changes affect terrestrial ecosystems? - How does vegetation interact with physical processes of the hydrological cycle? - How will changes in landuse, sea level and climate alter coastal ecosystems, and what are the wider consequences? - How do ocean biogeochemical processes influence and respond to climate change? - What significant climatic and environmental changes occurred in the past, and what were their causes?	• International program to support global scale assessment activities of the Intergovernmental Panel on Global Change • Scientific underpinning of international policymaking in collaboration with Human Dimensions of Global Environmental Change, and World Climate Research Program
8.	Economic Commission for Europe, Environment and Human Settlements Division, Air Pollution Section	• Regulatory action under the Convention on Long-Range Transboundary Air Pollution on emissions and fluxes of No$_x$ VOCs and heavy metals • Monitoring and modelling of air pollutants • Emission verification and monitoring of Parties' commitments • Accommodation of new member governments in ECE (now 54 countries)	• Review and evaluation	• Report, annual meetings of the executive body
9.	World Health Organization, Global Environmental Monitoring System	• Drinking water quality • Recreational water quality • Eutrophication • Microbiological pollution • Urban water management • See Table 9	• Expert meetings to design and develop global water quality monitoring	• Progress reports on the implementation of the Mar del Plata Action Plan and Strategy • Global assessments in support of U.N. agency programs. UNEP, WHO, UNESCO, WMO

ACRONYM LEGEND:

ECE	= Economic Commission for Europe	HDGECP	= Human Dimensions of Global Environmental Change
IGBP	= International Geosphere-Biosphere Program	NGO	= Non Government Organization
U.N.	= United Nations	U.S.	= United States
UNEP	= United Nations Environment Program	UNESCO	= United Nations Educational, Scientific and Cultural Organization
WHO	= World Heath Organization	WMO	= World Meteorological Organization

Table 8, *continued.*

Science Advisory Board's Workgroup on Emerging Issues: Summary of International Responses

	AGENCY	PRIORITIES	PROCESS	ACTION
10.	International Union for the Conservation of Nature	• Threatened species • Protected areas • Geology • Sustainable development • Environmental law • Environmental education and training	• Membership organization involving scientists and experts from government agencies, NGOs, and research institutions from 120 countries • Field projects to demonstrate the wise use of natural resources	• Advisory • Collaborates with Ramsar Convention Bureau on the Convention on Wetlands of International Importance, especially as waterfowl habitat (the Ramsar Convention); 23 contracting Parties in 1980 to over 70 in 1993
11.	Swedish Environmental Protection Agency / Swedish Council for Planning and Coordination of Research	• View of nature	• Expert consultation	• Knowledge dissemination
12.	Royal Society of Canada, Canadian Global Change Program	• See Table 10 (CGCP 1992)	• Expert consultation	• Canadian contribution to IGBP and HDGECP
13.	Report of Canada to the United Nations on Sustainable Development	• Implementation of Agenda 21	• Information sharing on UNCED commitments by reporting to the U.N. Commission on Sustainable Development	• National reports 1993-1997 to prepare for a U.N. review of progress in reaching the goals of the Earth Summit
14.	U.K. Global Environmental Research Office	• Population change and socio-economic dimensions • Methodological approaches • uv-B • Agricultural impact • Biodiversity • Redistribution of pests, pathogens and diseases • Soils as sources and sinks • Improvement in coastal engineering • Cities and sustainability • Energy alternatives	• Research framework	• Advisory

ACRONYM LEGEND:

ECE = Economic Commission for Europe
IGBP = International Geosphere-Biosphere Program
U.N. = United Nations
UNEP = United Nations Environment Program
WHO = World Heath Organization

HDGECP = Human Dimensions of Global Environmental Change
NGO = Non Government Organization
U.S. = United States
UNESCO = United Nations Educational, Scientific and Cultural Organization
WMO = World Meteorological Organization

Table 9.
General Characteristics of Major Water Quality Issues on a Global Scale

Quality issue	Water bodies mostly concerned	Major problem area	Time-lag between causes and effects	Space scale of issue[a]
Pathogenic agents	++rivers +lakes +groundwaters	++health	<1 year	local
Organic pollution	++rivers +lakes +groundwaters	++aquatic environment	<1 year	local
Salinization[b]	++groundwaters +rivers	++most uses +aquatic environment +health	1-10 years	regional
Nitrate pollution	++groundwaters +rivers	+health	>10 years	regional
Heavy metals	all water bodies	+health +aquatic environment +ocean fluxes	<1 to >10 years	local to global
Pesticides and industrial organics	all water bodies	+health +aquatic environment +ocean fluxes	1 to 10 years	local to global
Acidification[a]	++rivers, lakes +groundwaters	+aquatic environment +health	>10 years	regional
Eutrophication[c]	++lakes +rivers	++aquatic environment +health	>10 years	local
Sediment load[d]	+rivers	+aquatic environment +most uses +ocean fluxes	1 to 10 years	regional
Hydrological modifications[e]	++rivers	++aquatic environment	1 to 10 years	regional

+	important issues on a global scale
++	very important issue on a global scale

[a] including atmospheric transport of pollutants
[b] including high fluoride or arsenic contents
[c] including river nutrient loads
[d] increase or decrease of loads
[e] water diversion, damming and over-pumping of aquifers

Source: WHO/UNEP 1991

Table 10.
Focal Points of the Canadian Global Change Program (CGCP) in Relation to Key Global Change Issues

	GLOBAL CHANGE ISSUES						
CGCP FOCAL POINTS	Climate Change	Energy and Resource Consumption	Air and Water Pollution	Stratospheric Ozone Depletion	Population Increase	Extinction Events	Land and Soil Degradation
Critical Zones	•	•	•	•	•	•	•
Data and Information Systems	•	•	•	•	•	•	•
Security	•	•	•	•	•		•
Renewable Resources	•	•			•	•	•
Ecosystem Research and Monitoring	•		•	•		•	•
Culture and Values		•	•		•	•	•
Arctic	•		•	•		•	
Climate, Oceans and Hydrology	•	•	•	•			
Energy	•	•	•		•		
Human Health	•		•	•	•		
Past Environments	•					•	

Source: CGCP 1992

Conclusion

These documents provide a list of issues that are or are not already being addressed by the IJC, but could be relevant to the Great Lakes. Several of the issues from the global survey are in common with our Survey of the Great Lakes Region (Table 9). Perhaps the most noticeable are various issues related to sustainable use and development expressed in the various documents. The biological effects of uv-B was also evident in both surveys. Several broad issues were apparent in the global survey that did not show up as high priority emerging issues in our Great Lakes survey. Two of note are: the broad issue of biodiversity and especially in relation to ecosystem function; and global climate change. The first, biodiversity, is closely related to a more specific issue being addressed in the Great Lakes and to some extent may be subsumed within it, i.e. invasions and effects of exotic organisms. The second is being addressed at an information level by the Workgroup on Emerging Issues and in previous Science Advisory Board reports, and is not a specific responsibility under the Great Lakes Water Quality Agreement.

Recommendation

The Workgroup on Emerging Issues recommends that:

- **the issues identified as potentially important for the International Joint Commission be considered as priorities for serious deliberations during the next biennium. They are complex issues, especially the issue of sustainability that reappeared in each survey, that would require IJC resources to address in terms of implications for progress under the Great Lakes Water Quality Agreement. The issues assessed as most salient include:**

1. sustainable development
2. stability of water levels
3. uv-B effects on biota
4. various implications of the **North American Free Trade Agreement** (NAFTA)
5. lifestyle choices as a factor in ecosystem integrity
6. incidence of endometriosis in women who eat fish from the Great Lakes.

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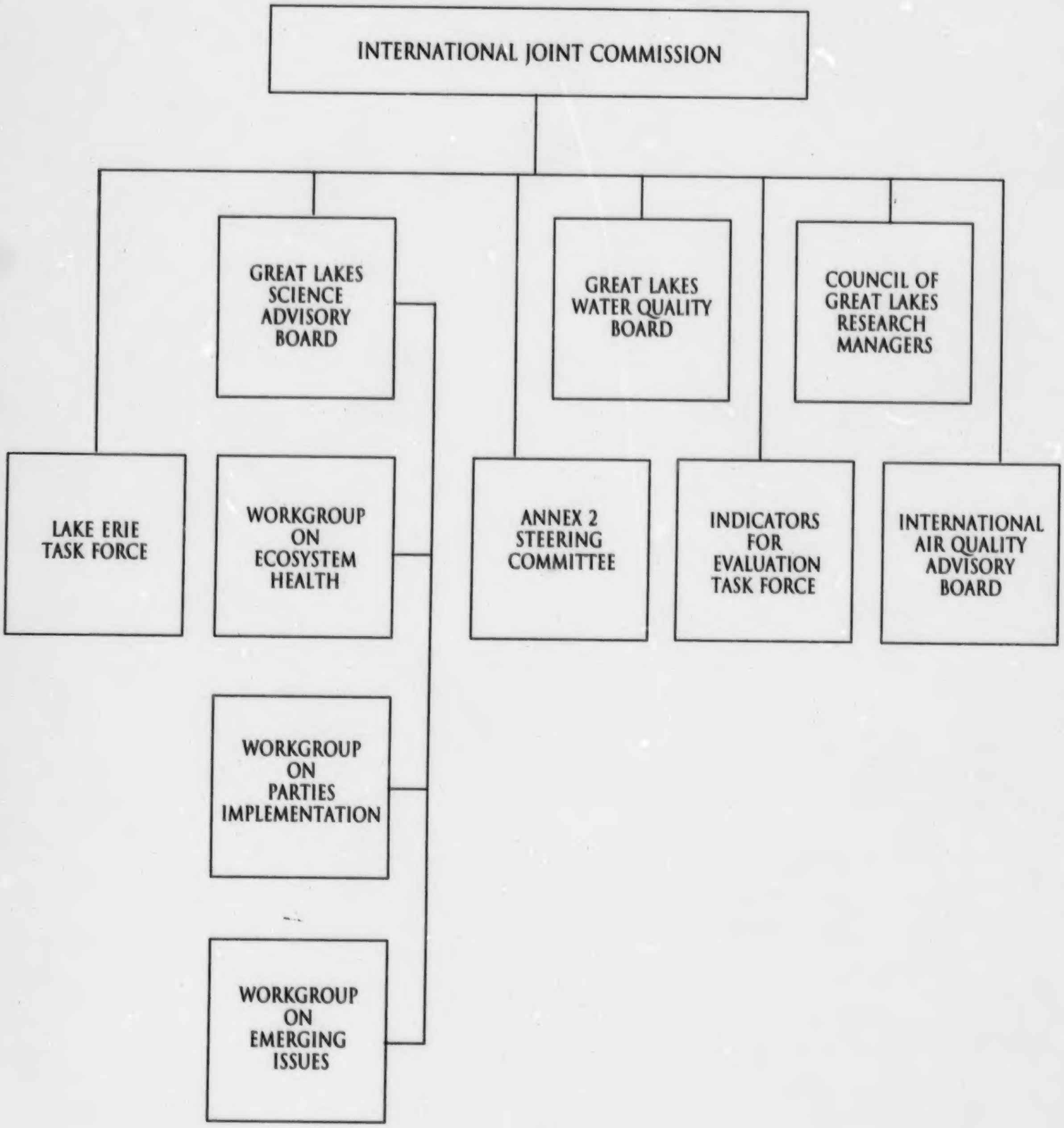
2.11 THE JOINT INSTITUTIONS AND OTHER ADVISORY ENTITIES REPORTING TO THE INTERNATIONAL JOINT COMMISSION

WITH GENERAL AND SPECIFIC MANDATES RELATED TO THE GREAT LAKES WATER QUALITY AGREEMENT: 1993-1995 PRIORITIES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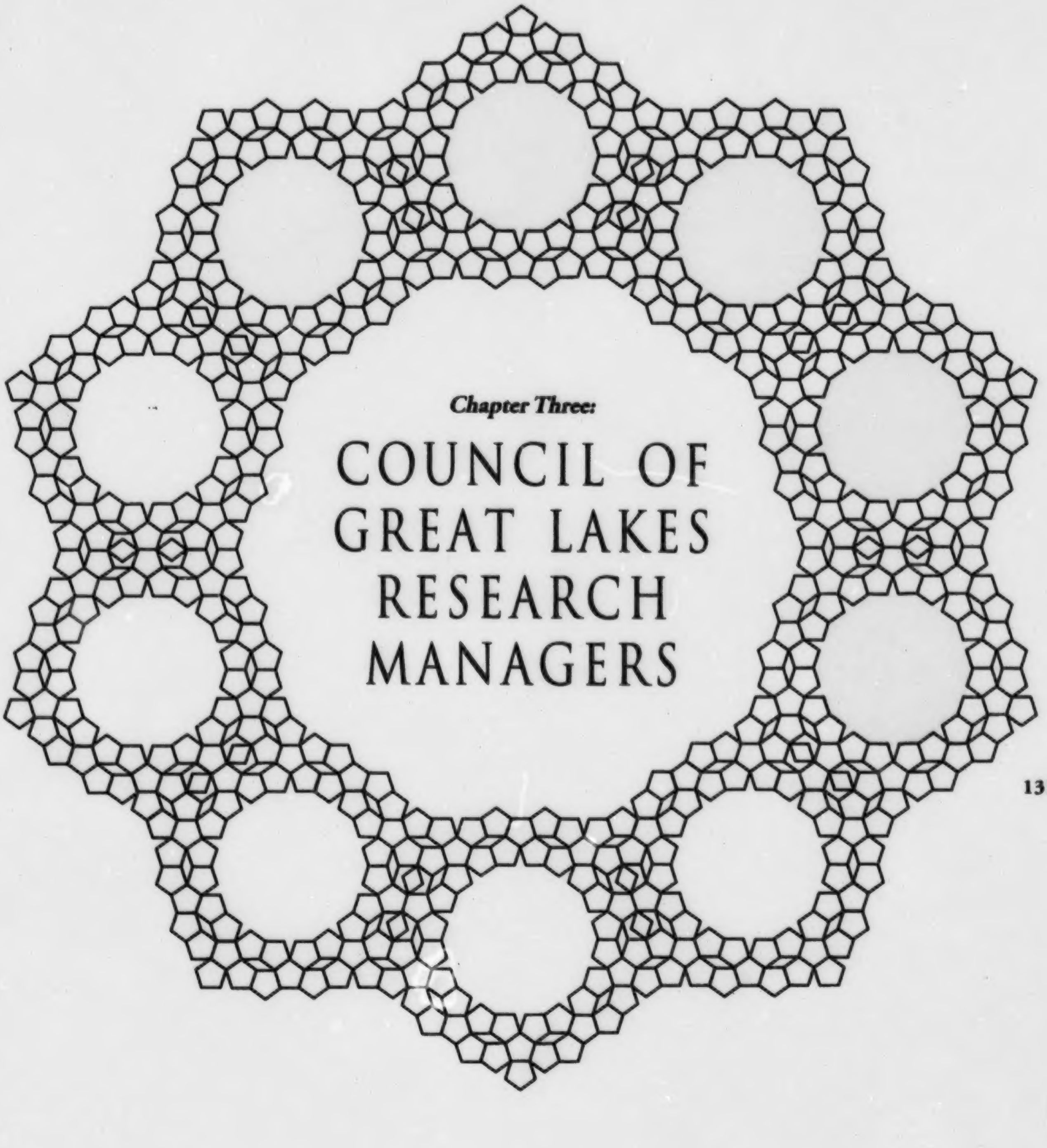
WORKGROUP ON PARTIES IMPLEMENTATION
WORKGROUP ON EMERGING ISSUES



Chapter Three:

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We can choose to pursue an aim or goal — such as the aim of understanding better the universe in which we live, and ourselves as part of it — which is autonomous of the particular theories or frameworks that we construct to try to meet this aim. And we can choose to set ourselves standards of explanation, and methodological rules, which will help us to achieve our goal and which it is not easy for any theory or framework to satisfy. Of course, we may choose not to do this: we may decide to make our ideas self-reinforcing. We may set ourselves no task other than one we know our present ideas can fulfil. We certainly can choose to do this. But if we do choose to do this, not only will we be turning our backs on the possibility of learning that we are wrong, we will also be turning our backs upon that tradition of critical thought (stemming from the Greeks and from culture clash) which has made us what we are, and which offers us the hope of further self-emancipation through knowledge.

To sum up, frameworks, like languages, may be barriers. They may even be prisons. But a strange conceptual framework, just like a foreign language, is no absolute barrier: we can break into it, just as we can break out of our own framework, our own prison. And just as breaking through a language barrier is difficult but very much worth our while, and likely to repay our efforts not only be widening our intellectual horizon but also by offering us much enjoyment, so it is with breaking through the barrier of a framework. A breakthrough of this kind is a discovery for us. It has often led to a breakthrough in science, and it may do so again.

— Karl R. Popper, *The Myth of the Framework: In defence of science and rationality (1994)*

3.0 COUNCIL OF GREAT LAKES RESEARCH MANAGERS ACTIVITIES

Introduction

The **Council of Great Lakes Research Managers** (Council) was established to enhance the ability of the Science Advisory Board to provide leadership, guidance and evaluation of Great Lakes research programs. The new terms of reference issued in 1991 directs the Council to compile a research inventory identifying research needs and to coordinate research projects. In addition to reporting on progress toward achieving our goals, we have expanded our geographical area of interest and membership to include the St. Lawrence River and thus now use the term, Great Lakes-St. Lawrence River Basin Ecosystem. Membership consists of individuals managing and coordinating research programs of federal, state and provincial governments in the United States and Canada, and representatives of private institutions.

3.1 RESEARCH ASSESSMENT

The Council of Great Lakes Research Managers was set up in 1984 to enhance the ability of the Commission to provide effective leadership, guidance, support and evaluation of Great Lakes research programs with particular reference to programs required or funded pursuant to the provisions of the **Great Lakes Water Quality Agreement** (GLWQA). The membership of the Council is comprised of persons responsible for research programs related to the implementation of the Agreement.

The International Joint Commission requested the Council of Great Lakes Research Managers to prepare an assessment of the adequacy of research relevant to the Great Lakes Water Quality Agreement. In response to this request for advice, the Council has focussed this review on significant developments in research on fish, wildlife and humans exposed to persistent toxic substances in the Great Lakes. In particular, there has been a significant advance in the funding and coordination of research, particularly in the field of human health.

3.1.1 Human Health

United States

In the United States, Congress amended part of the Federal Water Pollution Control Act in 1990 to include the provisions of a Great Lakes Critical Programs Act. Part of that act mandated the **Environmental Protection Agency** (EPA), the **Agency for Toxic Substances and Disease Registry** (ATSDR), and the Great Lakes States to submit a report to Congress by September 1994. The report (Agency for Toxic Substances and Disease Registry, in prep.) was to contain an assessment of the adverse effects of water pollution on the health of people living in the Great Lakes States. Congress authorized annual funding of up to $3 million to support preparation of this report.

The Agency for Toxic Substances and Disease Registry (1994) received $2 million for fiscal year 1992 and $3 million for each of the years 1993 and 1994 to support research studies on the effects of pollutants on human health in the Great Lakes basin. These ATSDR research activities are consistent with the overall mission of ATSDR, which is to prevent adverse health effects and diminished quality of life associated with human exposures to hazardous substances from waste sites, unplanned releases and other sources of pollution present in the environment.

The Council of Great Lakes Research Managers endorses the Great Lakes Health Effects Research Strategy developed by the ATSDR. The goals of this strategy (DeRosa and Johnson, in press) are to identify human populations residing in the Great Lakes basin that may be at greater risk of exposure to chemical contaminants present in one or more of the Great Lakes, and to help prevent any adverse effects. This strategy is built on the following five traditional elements of disease prevention:

- Identification of patterns of morbidity and mortality
- Evaluation of causal factors accountable for the observed pattern of morbidity or mortality
- Control of the factors found or thought to be accountable for the observed morbidity and mortality
- Dissemination of information about the identification, evaluation, and control of the observed pattern of morbidity and mortality, and
- Infrastructure to support the identification, evaluation, control, and dissemination elements of disease prevention. This strategy has been adopted by the International Joint Commission as a framework for the study of effects of contaminants on human health and on other organisms in the Great Lakes basin.

In fiscal year 1992, ATSDR funded eight epidemiological investigations and a ninth study to develop more sensitive methods to detect persistent contaminants in human biological tissues and fluids. In fiscal year 1993, a tenth grant was added to establish an interlaboratory program for quality control and quality assurance for the other nine research investigations.

The awards fall into two broad categories: environmental and epidemiological studies. The purpose of the environmental studies is to characterize exposure pathways for the pollutants in the basin, with an emphasis on developing some new methods that will permit a more rigorous assessment of the relationship between those pathways and specific body burdens of the toxic substances.

The epidemiologic investigations are to characterize exposure as well as human health outcomes in susceptible populations. They were intended to expand on existing cohort studies to the extent feasible and to assess the potential for subtle forms of toxicity increasingly of concern in the basin, including neurobehavioural, developmental, reproductive and immunotoxic effects, including the potential for transgenerational impacts. The potential for transgenerational effects (including neurobehavioural deficits) is perhaps one of the more challenging problems confronted by health researchers, due to the potential influence of both paternal and maternal exposures that result in adverse health effects.

Of six existing cohorts supported by the awards made to date, three are cohorts of sport anglers in the states of Michigan, New York and Wisconsin; two represent cohorts of Native American Indians, the Mohawk Indian and the Red Cliff Indian tribes, along with a cohort of breastfeeding mothers in New York State.

The awards also established two new cohorts. One of these, the Illinois cohort of African American women, is a study intended to define the relationship between body burdens of mothers and health effects in infants. The other is the Michigan cohort of reproductive-age men and women, age 18 to 34. A final award is intended to enhance analytical methodology, specifically to discriminate among the dioxin-like coplanar PCBs and the non-coplanar PCBs within that broad class of compounds. Collectively, these awards will characterize exposure to the Great Lakes contaminants for all 11 of the critical contaminants identified by the International Joint Commission, including PAHs, alkyl lead, PCBs (including 67 congeners), and dioxin.

These grants also encompass the vulnerable populations that have been identified in collaboration and consultation with ATSDR's Board of Scientific Counselors. These populations include sport and Native American anglers, pregnant women, nursing mothers, fetuses and infant children, the urban poor, men and women of reproductive age, and the elderly.

Canada

The **Great Lakes Health Effects Program** (GLHEP) is a Health Canada initiative established in 1989 in response to health issues addressed in the 1987 Protocol to the Canada-United States Great Lakes Water Quality Agreement. Phase I (Health Canada 1994) of this multidisciplinary program covered a five-year period (1989-1994) and was allocated funding of $20 million. It combined research and action in partnership with the Canadian public and communities of the Great Lakes basin, and with agencies in Canada and the United States, to reduce the risk to human health from contaminants present in the Great Lakes.

GLHEP's mission "to protect human health in the Great Lakes basin from the effects of exposure to environmental contaminants" gave rise to three major **goals**:

- to determine the nature, magnitude and extent of effects on human health associated with exposure to contaminants (chemical, microbiological, radiological) from all sources of pollution in the Great Lakes basin

- to develop and implement strategies to reduce or eliminate risks to human health related to pollution in the Great Lakes basin, and

- to increase communication and consultation among agencies and the public, and to provide timely, useful information to foster understanding and appropriate action on health and environmental issues.

GLHEP-supported research involving measurements of organochlorine chemicals in human adipose tissue, breast milk and blood has confirmed that humans in the Great Lakes basin are exposed to persistent toxic chemicals through the air we breathe, the water we drink, and the food we eat. The latter accounts for approximately 80-90% of human exposure to most persistent organochlorine contaminants. This proportion may be even higher for consumers of large quantities of Great Lakes fish or wildlife, in which these contaminants can readily bioaccumulate.

Epidemiologic studies have helped to identify several subpopulations at higher risk of adverse health effects because of their greater exposure to Great Lakes contaminants or their increased susceptibility. In addition to consumers of large amounts of contaminated Great Lakes sport fish or wildlife, people living in large or industrial urban areas, the elderly, the sick, young children, pregnant women, the developing fetus, and newborns/infants of mothers who consumed contaminated Great Lakes fish have been identified as subpopulations at higher risk for health effects. These health effects include exacerbated respiratory disease, immune system impairment, neurological developmental delays, psychosocial disorders, reproductive anomalies, and possibly others.

Studies conducted over the first five years of the Great Lakes Health Effects Program indicate that adverse reproductive, developmental and immunological effects, among others, may potentially result from exposure to Great Lakes contaminants, particularly in those belonging to the higher risk groups mentioned above.

The ways by which we measure health are also changing. Traditional health outcomes such as cancer and birth defects, which are well recorded (Health Canada 1995), are comparatively insensitive indicators of the effects of long-term low-level exposure to environmental contaminants. Increased interest in and attention to the more subtle potential health effects of chronic low-level exposures to mixtures of chemicals are evident in current and future research directions. These include the study of effects associated with hormone alteration, stimulation or mimicry, genital development, endometriosis, sperm abnormalities, sub-clinical immune dysfunction, respiratory effects, neurobehavioural and child development, and psycho-social health. People's perceptions of their health and the effects on social structures and functions are as direct as clinically demonstrated disease conditions. These findings form the basis for further study of these evolving issues, and serve as a valuable contribution to ongoing research on the human health impact of environmental contaminants in the Great Lakes basin.

3.1.2 Fish and Wildlife Toxicology

Reconsiderations of the Role of Contaminants on Salmonid Reproduction

The 1987 Protocol to the 1978 Great Lakes Water Quality Agreement introduced the concept of ecosystem objectives as part of the Supplement to Annex 1, which is concerned with the development of specific objectives. Progress on the development of these ecosystem objectives has been slow, but there are two species that have been accepted by the Parties as ecosystem objectives in relation to Lake Superior. These are the lake trout and a small crustacean called *Pontoporeia hoyi*. The acceptance of the concept of ecosystem objectives has had the potential of changing the focus of the Agreement from specific pollutants to the whole range of physical, chemical and biological factors in the Great Lakes basin ecosystem that could affect or could have affected species. There has been considerable progress in the past decade to investigate the role of a variety of factors that may control and may have controlled the status of lake trout, not only in Lake Superior but also in the other Great Lakes.

Lake trout stocks in the Great Lakes basin were extremely valuable species for the commercial fisheries until their demise between 1940 and 1960. The indigenous populations of lake trout from Lake Ontario and Lake Erie are extinct and the present populations in those and other lakes are maintained through plantings of hatchery-reared fish. The demise of the lake trout stocks in most parts of the Great Lakes has been attributed to the depredations of the sea lamprey, overfishing, eutrophication and destruction of the physical habitat. The Great Lakes Fishery Commission was formed in the mid-1950s to develop and implement control measures on the populations of sea lamprey. One of the stated goals of the Great Lakes Fishery Commission is the restoration of self-sustaining stocks of lake trout to the Great Lakes, but the attainment of this goal has been elusive. Recently, the Great Lakes Fishery Commission has been reconsidering the possible role of environmental contaminants in the demise of the lake trout, particularly through disruption of reproductive processes. The possible role of environmental contaminants in the demise of the lake trout stocks and in the failure to reestablish self-sustaining populations is therefore of immediate interest to those involved in advising the International Joint Commission on progress in research relevant to the Great Lakes Water Quality Agreement.

Lake trout is not the only species for which fisheries researchers are reconsidering the possible role of contaminants in reproductive failure. In the past 25 years a large sport fishery has grown for a variety of salmon introduced from the Pacific coast. Like most lake trout stocks, most Pacific salmon stocks have been maintained through plantings of young fish from hatcheries, since there is practically no recruitment to the stocks from fish raised in the lakes. In recent years, a series of severe failures in hatcheries rearing Pacific salmon from broodstock taken from the Great Lakes has occurred. Some of the shortfall in production has been supplemented by importation of eggs from the Pacific coast. But this importation has been severely restricted because of the possibility of transporting new diseases into the Great Lakes. For example, the introduction of bacterial kidney disease, which has devastated stocks of coho salmon in Lake Michigan, is suspected to have entered the Great Lakes through shipments of new eggs. Thus, fisheries researchers and hatchery managers are urgently seeking a solution to, and the cause of, this reproductive failure characterised by a severe incidence of mortality during the early life stages.

The Great Lakes Fish Health Committee of the Great Lakes Fishery Commission recently hosted two workshops on what has come to be known as "Early Mortality Syndrome" (Hnath 1994). One of the first problems that the participants confronted was the definition of the syndrome and the possibility that there might be more than one syndrome. The following is the consensus definition developed by the workshop participants:

> "Excess mortality (beyond expected losses) is occurring from the eyed egg stage through the period of first feeding, which cannot be explained by rearing environment, husbandry or infectious diseases. The primary indicators are above-normal loss of eyed eggs, loss of fry at hatch, and loss of fry from hatch to feeding. Clinical signs may include hyperexcitability, anemia, spiral swimming, dark coloration, lethargy (laying on the bottom or the surface), emaciation, feeding difficulties, and deformities."

There is not a high degree of specificity in this broad definition, and there is no lesion that is specific for the diagnosis of this syndrome. In addition, the affected fry may have signs similar to other diseases such as blue-sac, which is an edematous condition of the yolk sac, coagulated yolk, and white spot.

Two groups of researchers have found an effective treatment for early mortality syndrome in salmonids. The signs of early mortality syndrome are similar to the signs of various vitamin deficiencies. A series of experiments to expose samples of eggs to different vitamins, including thyroxine, astaxanthin, beta carotene treatments and thiamine, was undertaken to determine whether they could prevent the onset of the signs. The only vitamin that was efficacious was vitamin B1 or thiamine (Fisher et al. in prep.). There is also some evidence that exposure of the eggs to solutions of the hormone thyroxine similarly protects the eggs from developing the signs. These findings indicate that there is some part of the carbohydrate or lipid metabolism of the developing embryo or fry that is being affected (Hnath 1994). Applying these results to hatchery practice may enable fisheries managers to restock the Great Lakes with salmonids and thereby save this valuable sport fisheries from collapse.

Workshop participants focused much of their attention on the possible causes of the syndrome and of the thiamine deficiency. The group considered as many possible causes of the disease as might be plausible, including: brood stock management; genetics, nutritional deficiencies and changes in the foodwebs; microbiological pathogens; and environmental contaminants. Through the use of epidemiological criteria originally developed for investigating the causes of human disease, the group was able to discard several possible agents. For example, there was no evidence from the microbiologists that a microbial pathogen was involved in the disease. Similarly, various lines of evidence indicated that the syndrome was not specifically related to some aspect of brood-stock management or genetics, even though certain strains of organisms seemed to be more susceptible. This left the possibility that the syndrome was related to some aspect of nutrition, either through changes in the Great Lakes food webs or through deficiencies, and/or an involvement of environmental contaminants.

This hypothesis is remarkably similar to the independently-derived conclusions of researchers in Swedish hatcheries working on an analogous syndrome, called "M74," of fry of Atlantic salmon from rivers flowing into the Baltic Sea. Swedish researchers (Norrgren 1993) have posed the question of whether high mortalities in eggs and fry, and other kinds of reproductive failure of other fish species in the Baltic and in the North Sea, might be related to these factors. For example, Baltic cod exhibit a high mortality of eggs and fry, fry of perch that have been exposed to effluents of pulp and paper plants have a high mortality, and burbot from the Gulf of Bothnia have a high incidence of retarded gonadal development leading to sterility. An inverse relationship has been reported between hatching success of whiting from the North Sea and organochlorine chemicals.

There is a wide diversity of opinion about the possible role of environmental contaminants on reproduction of wild or feral fish stocks in the Great Lakes. Until recently, the consensus among fisheries managers was that environmental contaminants were not an important factor. Within the past five years, a series of toxicological experiments have laid the basis for a retrospective risk assessment that is challenging this consensus. Eggs of lake trout are among the most sensitive organisms to exposures to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. There is a sharp increase in the embryo mortality above 50 parts per trillion in the eggs, and complete mortality in eggs with 100 part per trillion (Walker et al. 1991). The questions now posed to the scientific community are: whether the release of dioxin into Lake Ontario contributed to the collapse of the overfished stocks of lake trout; whether other stocks and other species in other locations were also affected; and what is causing the thiamine deficiency.

Micro-contaminants in Lampricides

The central policy of the Great Lakes Water Quality Agreement is that the discharge of any or all persistent toxic substances shall be virtually eliminated. One of the properties of some persistent toxic substances is that they induce the level of activity of liver enzymes responsible for detoxifying chemicals. This induction of **mixed function oxygenase** (MFO) activity in liver samples from fish and other organisms has been used extensively to indicate the presence of persistent toxic substances, such as **polychlorinated biphenyls** (PCBs), dibenzo-*p*-dioxins and furans, in the Great Lakes environment.

An intensive series of studies was undertaken by fisheries researchers during the 1980s and early 1990s to determine the identity of substances that caused MFO activity in fish, associated with the effluent from pulp and paper operations. Much of this work has been undertaken at pulp and paper mills located on the shores or tributaries of Lake Superior (Munkittrick et al. 1992, 1994 and Servos et al. 1994). Fisheries researchers found that fish from Whitefish Bay and

Batchawana Bay, pristine areas that are remote from pulp and paper operations, had elevated levels of MFO activity. After further study, research may determine that lampricides may have been responsible for elevated MFO activity.

Lampricides have been used for more than 30 years to reduce larval lampreys in nursery streams. **Three-trifluoromethyl-4-nitrophenol** (TFM) has been applied to most nursery streams on a three-year cycle, at a rate of 50 tonnes per year. The other substance is 2',5-dichloro-4-nitrosalicylanilide, which has a trade name of Bayer 73, and may be applied alone or in combination with TFM.

By placing white suckers in cages in streams being treated with lampricides, fisheries scientists showed that there was a five-fold induction of MFO activity two days after exposure (Munkittrick et al. 1994). These findings were confirmed in laboratory experiments using the same batch of lampricide. The technical formulations of TFM showed this biological activity, in contrast to the Bayer 73 formulations, which showed none of this activity. By using **high performance liquid chromatography** (HPLC), chemists isolated the TFM from the TFM formulations and demonstrated that it did not induce MFO activity. It was concluded that the activity was caused by other chemical compounds in the technical formulations (Servos et al. 1994).

Analysis of the TFM formulation showed that there was no detectable level of polychlorinated dibenzo-*p*-dioxins, furans and polynuclear aromatic hydrocarbons. These findings indicated that the contaminants in the lampricide were not one of the substances that have previously been known to cause MFO induction in the Great Lakes environment.

Significant progress has been made in isolating and identifying the chemical(s) in the TFM formulations responsible for the MFO activity. Through fractionation using solid phase cartridges, the TFM was removed from the formulation and the MFO activity shown to be associated with two distinct fractions, indicating the presence of at least two substances that have MFO activity. The major substances in the fractions were diphenyl ethers, but when these compounds were synthesized they were shown not to induce MFO activity in fish. It was concluded that the compounds associated with the MFO induction must be minor components of the TFM formulation, and that these compounds would be at very low concentrations in the receiving waters of Lake Superior after application to the tributaries.

Further fractionation with HPLC and analysis with high resolution gas chromatography/mass spectrometry has lead to preliminary identifications of several chemicals, including additional chlorinated diphenylethers and chlorotrifluoromethylnitro-*p*-dioxin. Substituting the dibenzo-*p*-dioxin structure with a trifluoromethyl or nitro groups only slightly changes — and may even enhance — the toxicity relative to a similarly substituted polychlorinated dibenzo-*p*-dioxin. These substances must be tested to determine their persistence and toxicity, and particularly their potential to cause metabolic disturbance such as the reduction of circulating sex steroids in fish.

Immunotoxicology

Introduction

In the past five years, the Great Lakes scientific community has become interested in the subtle effects of chemicals on the structure and functioning of exposed organisms. Toxicologists have long been interested in the quantities or concentrations of chemicals that directly caused increased mortality. More recently, they have turned their attention to the more subtle changes that can be detected at lower concentrations, particularly in offspring (Colborn et al. 1993). A new appreciation has developed of the ways in which these subtle effects can have devastating implications for populations of valuable fish and wildlife resources. The development and functioning of the immune system is one of these subtle endpoints, and toxicologists have made some remarkable advances in this science in relation to effects on fish and wildlife in the Great Lakes.

A functional immune system is essential to defend against pathogenic agents and cancer. Exposure to chemicals that are immunotoxic may result in increased susceptibility to disease because the immune system's competency is compromised and its resistance to disease is diminished. Aquatic environments, such as the Great Lakes, facilitate the survival and dispersal of pathogens that infect aquatic organisms. Thus, the competency of the immune system of aquatic organisms such as fish is particularly important, because they are continually presented with challenges from pathogens. Subtle changes in the immune system, caused by exposures to chemicals, may lead to outbreaks of disease in aquatic organism populations (Anderson and Zeeman, 1995).

The immune system is particularly vulnerable to chemically-induced damage because the cellular components continually grow and differentiate during development and throughout the life cycle of the organism. In addition, the immune system has a "memory," and repeated or chronic, low-level exposures to immunotoxic chemicals may have more of an effect on the survival and functioning of organisms than a single, acute exposure to a higher concentration (Weeks et al. 1992).

Immunotoxic Chemicals

Many environmental chemicals have been shown, particularly in mammals, to affect or modulate the development and functioning of the immune system. The major classes of compounds that have been identified as immunomodulators include pesticides, polynuclear aromatic hydrocarbons, organochlorine compounds such as polychlorinated biphenyls, and organometallic compounds such as tributyl tin (Dunier and Siwicki, 1993). While the science of immunotoxicology in fish is still in its infancy, chronic, low-level exposure of fish to pesticides and polynuclear aromatic hydrocarbons has been suspected for some time of predisposing fish to disease through immunosuppression.

For example, several experimental studies have established the immunomodulatory effects of polychlorinated biphenyls in fish. In one study, Aroclor 1232 was injected intraperitoneally into channel catfish (*Ictalurus punctatus*) that had been immunized with an attenuated strain (bacterin) of *Aeromonas hydrophila* (Jones et al. 1979). The PCB-treated fish showed reduced functioning of the macrophages, and when challenged again with *Aeromonas hydrophila*, all exposed fish died, while the controls survived. These results indicate a lack of response to the bacterin and a decrease of phagocytic function in exposed fish. The experiment demonstrated that this PCB suppressed the normal functioning of the immune system in the treated fish.

Similarly, there are several examples of experiments in which organophosphate and carbamate compounds have caused immunomodulatory effects in fish. Exposure of lake trout and coho salmon to malathion decreased spleen weight and size, and the numbers of lymphocytes in the spleen (Zeeman and Brindley, 1981). Carp exposed to trichlorfon exhibited suppression of immune function (Siwicki et al. 1990). However, dichlorvos, a known immunosuppressor in certain mammals, did not (Cossarini-Dunier et al. 1991). Salmonids exposed to carbaryl at 10.2 ppm for 100 days showed atrophy of lymphoid organs and depletion of lymphocytes. Spot exposed to the much lower concentration of 0.1ppm showed a significant increase in susceptibility to parasitism by sporozoans (Walsh and Ribelin, 1975).

Indicators

Measuring the immune system components or cellular function provides a very sensitive endpoint of exposure to environmental contaminants (Weeks et al. 1992). For example, immunotoxic chemicals may cause suppression or enhancement of the immune system, affect the ability to produce antibodies through the humoral system, or the ability of macrophages to clear pathogenic microbes. Macrophages provide the first line of defense against infectious agents, and are thus an especially important component of the fishes' immune system. Similarly, the activation of leukocytes is a critical component of immune system functioning. Measurements of macrophage functioning and of the activity of white blood cells have been used as sensitive indicators of effects of chemicals in aquatic environments.

For example, fish from the Elizabeth River in Virginia, which is highly polluted with polynuclear aromatic hydrocarbons, have a high incidence of disease and neoplasms, which often indicates immune system dysfunction. Tests of macrophage function were used to compare the immune competence of fish captured from the Elizabeth River with fish captured from the relatively unpolluted York River (Weeks et al. 1986). Macrophage function was significantly depressed in three different species living in the Elizabeth River compared to fish from the York River. Similarly, mummichog (*Fundulus heteroclitus L.*) from the Elizabeth River showed suppression of the activity of a subset of white blood cells (natural cytotoxic cells) that are important in tumor surveillance, compared to the fish from the York River (Faisal et al. 1991). Thus, assays of macrophage function and natural cytotoxic cell activity in captured fish proved to be sensitive indicators of the effects of toxic chemicals in this aquatic environment.

Another study investigated the likely effect on mammalian predators of contaminated fish. Coho salmon (*Oncorrhynchus kisutch*), which had accumulated a variety of halogenated aromatic hydrocarbons, were fed to mice. The mice were immunized with red blood cells from sheep to assess whether this exposure to contaminants led to immunosuppression. While no effect was seen on lymphocyte numbers, antibody response was depressed proportionally to the elevated contaminant levels (Cleland et al. 1989).

Other Endpoints

In the past, many non-specific indicators of immune compromise have been linked with exposure to environmental chemicals in fish (Dunier 1994). These endpoints have included decreases in the size of the spleen, in the leucocyte counts and in the phagocytic ability of the macrophages. Similarly, decreases in the levels of plasma proteins have been recorded, which can reflect a lower level of circulating antibodies.

Several examples of these changes are available from experiments with organochlorine chemicals. Goldfish exposed to DDT have shown a decrease in immunocompetence as demonstrated by a decrease in plasma proteins, decreased spleen weight and suppression of the antibody response when exposed to a foreign antigen, bovine serum albumen (Zeeman and Brindley, 1981). Salmon exposed to 0.35 ppb of endosulfan for 25 days had atrophy of lymphoid organs and a decrease in the number of white blood cells (Zeeman and Brindley, 1981). Channel catfish exposed to mirex (21 or 42 mg/kg/day) had decreased counts of leucocytes and thrombocytes (Zeeman and Brindley, 1981). Exposure of trout to endrin has caused a decrease in lymphocyte response (Bennett and Wolke, 1987). Catfish exposed to lindane (1.3mg/l) showed a significant reduction in leucocyte count and antibody response to *Aeromonas hydrophila* (Saxena et al. 1992).

In the Great Lakes basin, no direct evidence yet exists as to whether or not PCBs are affecting the immune system of introduced Pacific salmon. An in vitro system has been developed, focused on the early events in the activation of lymphocytes from the spleen of chinook salmon when stimulated with compounds that induce mitosis (Noguchi et al. 1995). Flow cytometry has been used to identify lymphocytes of bursa and thymic origin and thereby to investigate the susceptibility of these cells to the specific PCB congeners. This technique will help in determining whether PCBs in the waters of the Great Lakes are contributing to the susceptibility of Pacific salmon to disease through effects on their immune status.

Research has been undertaken on the immune status of fish-eating birds in the wild and exposures to environmental contaminants (Grasman 1995). In herring gull adults and chicks from various locations across a wide range of concentrations of organochlorine compounds, the heterophil to lymphocyte ratio decreased as a physiological index of contaminant exposure increased. In the chicks the mass of the thymus decreased as the index of the contaminant exposure increased. These results indicated that the immune systems in this species had been affected by the contaminants, though neither response was specifically correlated with the concentration of PCBs in the liver. The competence of the immune system was measured in herring gull and Caspian tern chicks by injecting phytohemagglut-inin, a mitogen derived from plants, into the skin of the wing and measuring the response after 24 hours. This is a measure of the immunity mediated through the cells from the thymic system. In both species the measured response on the skin showed that immunity decreased as the egg PCB concentrations increased. Both the field observations of thymic atrophy and the suppression of the immune response mediated by the thymic system are consistent with the effects of PCB and dioxin in laboratory animals.

3.1.3 Status of the Research Inventory

Since the Great Lakes Water Quality Agreement was first signed in 1972, a continuing terms of reference has included examining and advising the Commission on the adequacy of research, and promoting research coordination. Over the intervening years a series of research inventories have been produced to meet these requirements. This responsibility has been a relatively resource-intensive undertaking and during the 1993-1995 biennial cycle the Council completed it through two of its member organizations, the National Oceanic and Atmospheric Administration and the Ontario Ministry of Environment and Energy. Staff at the Great Lakes Regional Office coordinate the requests for information from the principal investigators and forward the information to these two agencies.

A series of changes has also occurred in the preparation of the research inventory. For example, information is now collected on research projects undertaken on a much wider variety of topics to reflect the ecosystem approach to management of the Great Lakes Basin Ecosystem. In addition to the research on pollution by nutrients, toxic substances and radionuclides, topics include the introduction of exotic species, land use and wetlands, shoreline and upland habitat, resource management including fisheries, wildlife and forestry, and natural ecological processes. These categories make up a new classification system.

In the past, it has been a challenge to produce and publish the research inventory in a timely manner. The cost has been substantial and the data have frequently been out of date by the time that the document was completed. In addition to undertaking the work through compatible binational systems within the two member agencies, the Council decided to make the inventory accessible through the **Great Lakes Information Network** (GLIN) and through computer disk, but not through written publication.

3.1.4 Recruitment, Training and Development of Scientists

The 3R's: Recruitment, Replacement and Retention of Scientists in the Great Lakes

In fall 1989, the Council of Great Lakes Research Managers convened a Vision Workshop at the Niagara Institute and identified the issue of the recruitment, replacement and retention of scientists as an important factor in the ability of the Great Lakes research community to undertake future research. While the International Joint Commission was setting priorities for the 1993-1995 biennial cycle, it requested the Council of Great Lakes Research Managers to examine the adequacy of current training programs to fill future needs for scientists for Great Lakes research.

The strengthening of the research community in the Great Lakes basin begins with the creation of a healthy research climate that attracts and holds expertise. That climate is established and maintained, in part, by the opportunities offered. It is not something that can be addressed only by the infusion of money, although that is a vital ingredient for the stability essential for good science. Nor can it be reasonably expected from the provision of physical facilities alone, although that can be useful to concentrate effort efficiently. And it is not something that can be initiated solely from a vision or mission statement, although that is often the basis for a commitment that sustains the scientist's effort, both personally and professionally. The processes necessary to strengthen research includes all these things but goes much further and leads to the establishment of a vigorous intellectual environment that by its own power attracts and develops skill, encourages initiative and provides incentive for innovation. In the field of ecosystem sciences, it is increasingly requiring transdisciplinary expertise and synthesis. This is what must be maintained and nurtured in the Great Lakes.

The current members of the scientific research community in the Great Lakes and St. Lawrence River comprise an aging population. The Council of Great Lakes Research Managers has raised the need to replenish this population with well-trained graduates prepared to investigate issues in a multidisciplinary manner. Although it is a significant challenge, a vigorous intellectual environment must be maintained in the Great Lakes region if the advances in scientific knowledge are to be applied to restoring and maintaining the integrity of the waters of the Great Lakes Basin Ecosystem. How can scientists be recruited from across the continent to work in the Great Lakes basin? How can graduate students be attracted? How can universities and government laboratories be properly persuaded that the basin requires their attention? And how can retraining be introduced to assist those who have decades of experience in addressing the changing needs of research?

U.S. Perspective

The Great Lakes Basin Ecosystem encompasses a large geographic area, and thus its research requires a large-scale approach with integrated and multidisciplinary programs. These large scale phenomena are expensive to investigate and control. In the 1960s, the United States federal government provided the funds, particularly to universities, to undertake the necessary research. In the present economic climate, it is not likely the federal government will have the funds to provide the economic incentives that previously sufficed.

Universities have a major responsibility for research on large lakes due to their expertise, unique equipment and facilities, including libraries, powerful computing capabilities, and major museums. They also develop future scientists whose research orientation is often determined while in school.

Supply

A review of the trends in recruitment and production of graduate students in disciplines germane to the Great Lakes is encouraging. Overall in the United States, enrollment in the earth, atmospheric and ocean sciences peaked in 1984 at about 15,655 students and has slowly declined to a low in 1989 of about 13,849 students. Students in the biological sciences remained fairly constant from 1975 through 1987, with a sharp increase from 47,138 in 1987 to 52,120 in 1991 (Table 1). Overall the trend was for a gradual increase from 61,547 in 1984 to 66,867 in 1991 (NSF 1992).

Graduate student enrollment in Ph.D. granting institutions from states bordering the Great Lakes provide a clearer picture of the enrollment trends of students that are probably going to be the major contributors to the pool of potential recruits. The science and engineering student enrollment overall has remained fairly steady from around 130,000 in 1983 until 1990, however there was a marked increase in enrollment to over 142,000 in 1991. Enrollment data from the four major institutions producing the bulk of the graduates in science and engineering in the basin provides a more precise figure, from the Universities of Wisconsin, Michigan, Minnesota and Ohio State. Overall enrollment in these four institutions, which are four of the five in the country with the highest enrollment in science and engineering, has continually increased at a slow rate from 1984 to 1991 (Table 1).

Based on these data alone, it would be very difficult to argue that there are not enough students graduating from universities in the basin to replace current Great Lakes scientists. There are, however, some problems. Even though the data does not indicate a serious overall problem, it is too general to determine whether there will be enough limnologists, ecologists or aquatic chemists in the future. What are the enrollments in the key disciplines needed in the basin? Barring evidence to the contrary, it is generally assumed that there is a direct correlation between the number of students in science and engineering and the numbers in any particular discipline.

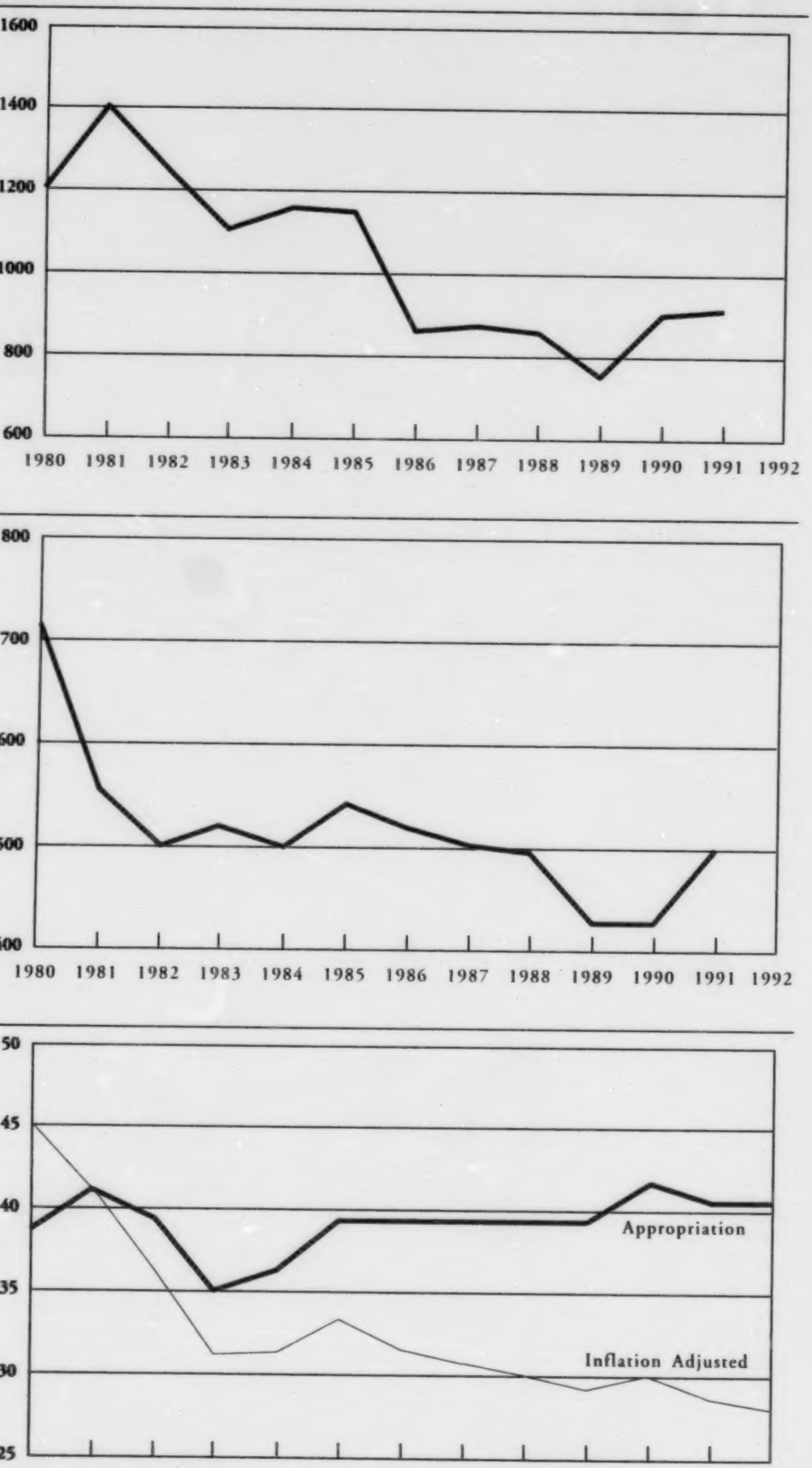
This data does not address the nature of the training or the quality of student being produced. It is reasonable to assume, however, that if there is a large pool of scientists from which to draw, those of a high calibre can be attracted to Great Lakes research if conditions are conducive. A more serious concern is that the National Sea Grant College

Table 1.
Graduate Enrollment in Science and Engineering in Four of the Major Ph.D. Granting Institutions in the Basin. (NSF, 1992)

YEAR	U. WISCONSIN*	U.MINNESOTA*	OHIO STATE*	U. MICHIGAN*	UNIV. IN BASIN TOTAL
1984	5,346	5,223	4,575	4,455	19,599
1985	5,181	5,595	4,739	4,557	20,072
1986	5,169	5,524	5,050	4,672	20,415
1987	5,220	5,320	5,088	4,882	20,510
1988	5,335	5,479	4,984	4,883	20,681
1989	5,506	5,607	4,926	5,079	21,118
1990	5,443	5,579	5,080	5,066	21,168
1991	5,914	5,720	5,439	5,252	22,325

* Four of the five universities in the U.S. with highest enrollment in science and engineering. The fifth is the University of Southern California.

Figure 1.
National Sea Grant College Program: Trends in number of principal investigators (1a), graduate students (1b), and effect of inflation on appropriations (1c).



1a.
Number of
Principal Investigators

1b.
Number of
Graduate Students

1c.
Effect of Inflation
on Sea Grant
Appropriations
(in $US millions)

Program in the United States has seen gradual declines in appropriations (inflation adjusted), number of graduates involved in the program, and the number of principle investigators undertaking research projects in the Great Lakes basin (Figure 1). Since Sea Grant is one of the primary supporters of Great Lakes academic research, changes in their funding and enrollment are particularly relevant.

Demand

The demand for research scientists within the Great Lakes basin is linked to funding of research. Government laboratories and agencies, state departments of natural resources and health departments are some of the primary government units supporting research. Additional research is accomplished within the universities by faculty investigators. The latter play an important role because they conduct research and train graduate students in activities relevant to the Great Lakes. Funding at this level has never been adequate or stable. University researchers have had to obtain funds in an opportunistic fashion, which precludes long-term studies and restricts work to studies of limited scope.

In addition, it is at the university where training for interdisciplinary research begins. Funding for this type of work has not been abundant. Improvement of basinwide research funding has the greatest potential for improvement of research.

Conclusions for U.S. Institutions

Overall enrollment in science and engineering in the nation as a whole, in universities in the states bordering the Great Lakes, and in the four major state universities in the basin all show a slow but definite increase in enrollment of graduate students in the sciences. No specific evidence indicates that there will be a shortage of students graduating in the disciplines needed to address Great Lakes problems. Declines in the funding of the Sea Grant Program, after adjustment for inflation, may limit the enrollment of graduate students in relevant areas.

Consequently, it appears that the supply side of the equation is adequate in the U.S. It makes sense, however, to encourage the development of as large a pool of scientists as possible from which to draw to insure the highest quality science that can be generated to address issues that have not yet been identified but that will inevitably require research in the future. More important to Great Lakes research is the lack of appropriate, stable, long-term funding and the need to create an intellectual climate that will attract good scientists to the region. The supply of young investigators is there. The senior scientists who can serve as mentors are still in place. The need lies in research funding which can bring them together.

Canadian Perspective

Managers of Canadian government research laboratories have expressed concern about the possibility of shortages of highly qualified scientists and engineers in the future. There is an uneven age distribution in the scientific community, with a large cohort of middle-aged scientists. Over the last 10 years, the rate of departure for scientists and engineers in the federal government varied between 4% and 5%. The retirement of the scientists from this cohort over a short period, in the near future, therefore might deprive the research and regulatory communities of a wealth of experience.

Supply

Enrollment in departments of biology and agriculture in Canadian universities increased by 16% in the 1980s (NSERC 1989). Similarly, enrollment in Canadian Ph.D. programs in the natural sciences increased significantly (AUCC 1991). Thus there is no indication of a likely shortage of qualified professionals to replace those who are about to retire.

Demand

Total federal government personnel on a national basis, engaged in activities in the natural sciences and engineering, increased from 24,405 in 1981 to a peak of 25,905 in 1984. There was, however, a 5% decrease by 1990-1991 to 24,628. The scientific and professional category, however, experienced a steady growth from 7,635 in 1981-82 to 8,719 in 1990-91.

Situation at Great Lakes Research Laboratories

Table 2 represents the findings of a poll on the perceived staffing requirements for university graduates at seven major federal and provincial government facilities undertaking Great Lakes research. Staff turnover is presently between 5 and 10% because of budget constraints. This rate might increase as the large cohort of middle-aged scientists reach retirement age within the next 5-10 years. In some years and in some organizations, up to one-half of the professional scientific staff may leave.

All laboratories, except fisheries, reported a sufficient quantity of graduates. Only the environment and wildlife laboratories, however, were satisfied with the quality of the candidates and did not feel the need for retraining.

Conclusions

- Many government research scientists will be retiring by the end of the 1990s.
- Overall production of science and engineering graduates in the basin has risen slightly over the past decade.
- There does not seem to be a shortage of qualified graduates to replace the present professionals when they retire.
- The timing to recruit qualified graduates to replace the professionals who are retiring in the next ten years may be crucial for the continuity of Great Lakes research.

Table 2.
University Recruitment Needs at Canadian Great Lakes Research Labs

	FEDERAL				**PROVINCIAL**	
	Water	**Human Health**	**Fisheries**	**Wildlife**	**Environment**	**Fisheries**
Staff Turnover						
At Present	5-10%	0.2	5%	10%	2-3%	5%
In 5-10 years	15-50%		5%	50%	2-3%	---
University Recruits						
Quantity	Too many	Good	Poor	Good	Good	Poor
Quality	Varies	Poor	Poor	Good	Good	Poor
Retraining	Yes	Yes	Yes	No	No	Yes

3.2.1 Application of the Ecosystem Framework to Zebra Mussels in Lake Erie

During the past five years, the Council of Great Lakes Research Managers has developed an ecosystem framework to aid managers in selecting priorities for research, and to assist policymakers to explore options. The Council, in collaboration with the United States Environmental Protection Agency and the Canada Department of Fisheries and Oceans, contracted with Dr. Steven Underwood and Dr. Richard Duke of the College of Architecture and Urban Planning at the University of Michigan in Ann Arbor, to undertake this developmental work. The objective was to develop a schematic diagram (see Figure 2) to link knowledge about the natural systems in the Great Lakes basin with societal and institutional processes and thereby aid in the selection of research priorities and policy options.

The Commission requested the Council of Great Lakes Research Managers to provide advice on applying the methodology to the issue of zebra mussels in Lake Erie as part of its 1993-1995 priorities. The Council held a workshop in Ann Arbor on January 17 and 18, 1995 to carry out this request.

Zebra mussels were inadvertently introduced into Lake St. Clair in 1986 when a European vessel exchanged ballast water. The species is indigenous to the Caspian Sea and had successfully spread to many parts of Europe. The zebra mussel is about 2.5 cm (1 inch) long and can form dense populations of more than half a million individuals per square meter on hard surfaces such as rocks, piers and sea walls, navigation buoys and boat hulls. Zebra mussels colonize the insides of water intake pipes and populations may grow large enough to block the flow of water to municipal drinking water plants and to industrial and power-generation facilities. The sharp shells have degraded the aesthetic quality of bathing beaches. By 1990, the zebra mussels had redistributed to other waterways as far away as New York, Louisiana and Oklahoma. The quagga mussel is a closely related species discovered later and which forms substantial populations on soft surfaces such as sediments.

The burgeoning populations of zebra and quagga mussels filter large quantities of water and remove the plankton. In Lake Erie, "catastrophic" declines have occurred in plankton populations and this has raised concerns that the major fisheries will be affected, since plankton is at the base of the food chain and therefore essential for the growth of juvenile fish. The effects of the mussels on Lake Erie food webs in Lake Erie could lead to the collapse of valuable fisheries such as the walleye, which is worth about $900 million annually.

Primarily in response to the introduction of zebra mussels into the Great Lakes, Congress enacted the Nonindigenous Aquatic Nuisance Prevention and Control Act in 1990. The Act establishes an interagency Aquatic Nuisance Species Task Force responsible for developing a framework to reduce the risk of unintentional introductions and to monitor and control nuisance species that are already in aquatic environments throughout the United States. In addition, Congress authorized five years of funding to support research on the effects of zebra mussels. This project of the Council of Great Lakes Research Managers was designed out of the need to create research priorities and was partly funded from the congressional authorization.

The implications of zebra mussels on the beneficial uses and ecology of the Lake Erie waters present a series of complex research and policy issues. Managers of research organizations may have a variety of perceptions and values toward a particular issue, and these may differ from those of regulatory officials, industrial representatives, academics and non-government organizations. If these various viewpoints are to be taken into consideration, the process of priority setting for research becomes complex. The Council workshop was designed to help various people representing diverse viewpoints and interests to examine the complex problem of recommending priorities for research on zebra mussels, and to come to decisions that were acceptable to all (Underwood and Duke, 1995a).

Before the workshop, participants addressed the process of reconciling research priorities for zebra mussels by participating in an exercise to introduce a philosophical discussion about managing ecosystems. This exercise was designed by Dr. Steven Underwood and Dr. Richard Duke and a team of coworkers at the College of Architecture and Urban Planning. It was modelled on the "games" that have been developed over the past four or five decades for understanding complex processes. The former Secretary of the Council of Great Lakes Research Managers, Peter Seidl, was influential in initiating and encouraging the development of this heuristic tool for understanding ecosystem management. Peter Seidl was on a leave of absence from the International Joint Commission with the World Bank when the plane in which he was travelling disappeared in the Bolivian jungle. As a tribute to the enthusiasm that Peter showed to his colleagues on this project, this exercise has been called the SEIDL Game. The acronym is comprised of the words Sustainable Environmental Integrative Development of the

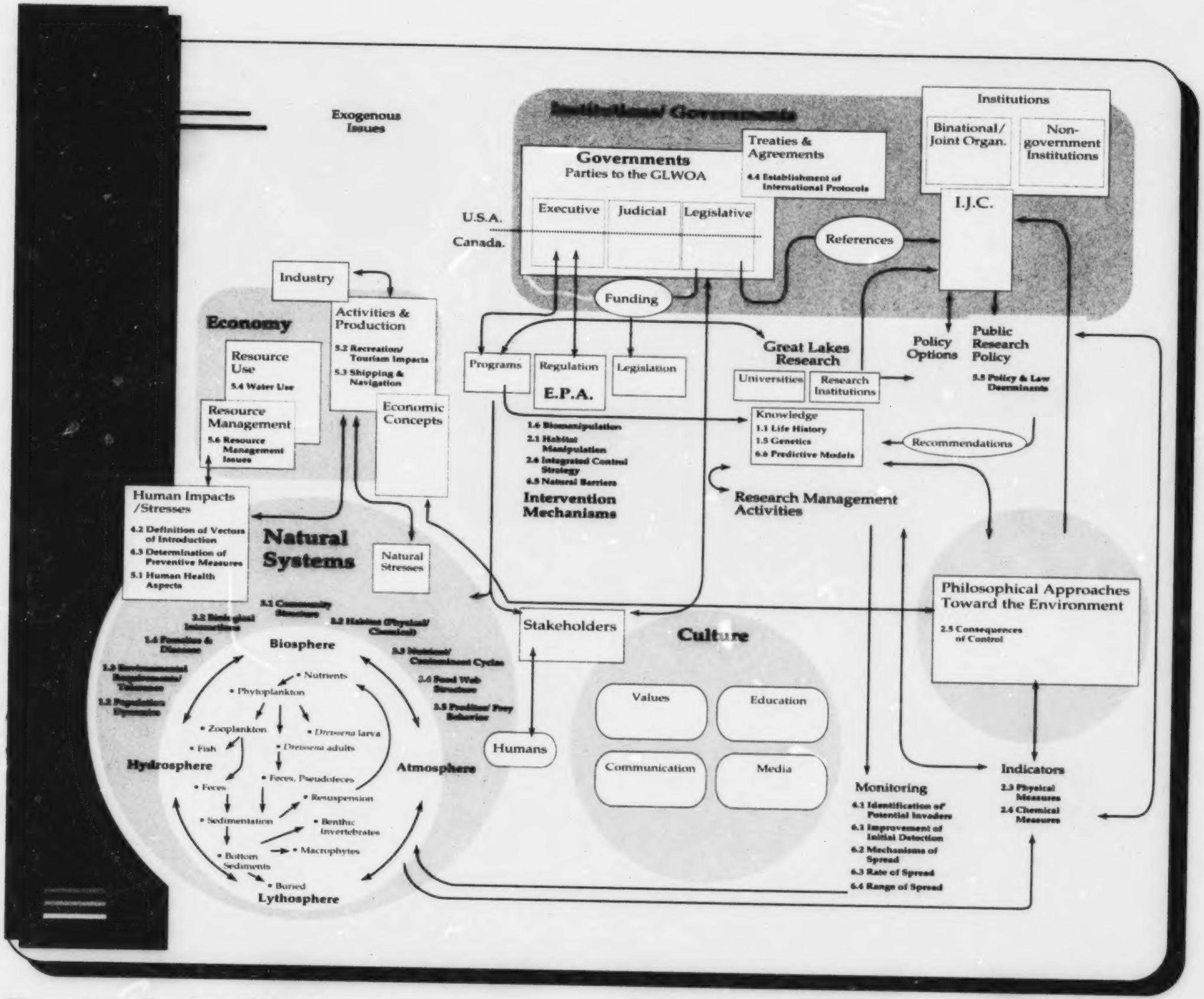

Exogenous Issues
Institutional/ Governments
Governments
Parties to the GLWOA
Executive
Judicial
Legislative
U.S.A.
Canada.
Treaties & Agreements
4.4 Establishment of International Protocols
Institutions
Binational/ Joint Organ.
Non-government Institutions
I.J.C.
References
Funding
Programs
Regulation
E.P.A.
Legislation
Great Lakes Research
Universities
Research Institutions
Policy Options
Public Research Policy
5.5 Policy & Law Determinants
Knowledge
1.1 Life History
1.5 Genetics
6.6 Predictive Models
Recommendations
Research Management Activities
1.6 Biomanipulation
2.1 Habitat Manipulation
2.6 Integrated Control Strategy
6.5 Natural Barriers
Intervention Mechanisms
Industry
Economy
Activities & Production
5.2 Recreation/ Tourism Impacts
5.3 Shipping & Navigation
Resource Use
5.4 Water Use
Resource Management
5.6 Resource Management Issues
Economic Concepts
Human Impacts /Stresses
4.2 Definition of Vectors of Introduction
4.3 Determination of Preventive Measures
5.1 Human Health Aspects
Natural Systems
Natural Stresses
3.1 Community Structure
3.2 Biological Interactions
1.4 Parasites & Diseases
1.3 Environmental Requirements/ Tolerances
1.2 Population Dynamics
2.2 Habitat (Physical/ Chemical)
2.3 Nutrient/ Contaminant Cycles
2.6 Food Web Structure
3.3 Predator/ Prey Behavior
Biosphere
Hydrosphere
Atmosphere
Lythosphere
• Nutrients
• Phytoplankton
• Zooplankton
• Dreissena larva
• Dreissena adults
• Fish
• Feces
• Feces, Pseudofeces
• Resuspension
• Sedimentation
• Benthic invertebrates
• Bottom Sediments
• Macrophytes
• Buried
Stakeholders
Humans
Culture
Values
Education
Communication
Media
Philosophical Approaches Toward the Environment
2.5 Consequences of Control
Monitoring
6.1 Identification of Potential Invaders
6.1 Improvement of Initial Detection
6.2 Mechanisms of Spread
6.3 Rate of Spread
6.4 Range of Spread
Indicators
2.3 Physical Measures
2.4 Chemical Measures

Figure 2. Ecosystem Schematic

Lakes. Copies of the reports (Underwood and Duke, 1995b) associated with the workshop, including the SEIDL Game, are available on computer disk.

The following is a summary of the workshop results. Twenty-one workshop participants were assigned to seven teams that each represented one of the following perspectives: ecophilosopher; physical scientist; policymaker; program manager; research manager; social scientist; and stakeholder. The participants considered and ranked the following six research foci, which were part of the proposed Aquatic Nuisance Species Program developed by the Aquatic Nuisance Species Task Force:

Biology/Life History of Nonindigenous Species

> "A basic understanding of the life history and population dynamics of recently introduced species is required in order to predict the response of the ecosystem to invasion, and to determine biological characteristics that may guide research to the discovery of effective, ecologically safe, and economically feasible control measures. Reviews of existing research literature in conjunction with primary biological research to consider the areas of life history, population dynamics, physiology and behaviour, genetics, parasites and diseases may be especially pertinent in determining an organism's vulnerability to particular control alternatives. Information on the ecological and environmental tolerances of species is necessary to determine the potential geographic limits of infestation and to predict which indigenous species and their habitats are most likely to be affected by the invasion.

Control and Mitigation of Nonindigenous Species

> "While temporary measures may mitigate the effects of invading organisms, the only truly effective means of control will be identified through long-term research. An example of this approach is the successful control of sea lamprey populations in the Great Lakes. Future success in controlling the damage from newly invading nonindigenous species must be predicated on the same research strategy which investigates the entire suite of physical, chemical and biological requirements of each nonindigenous species. Innovative and effective control techniques specifically targeted to nonindigenous invaders can only be determined through knowledge of the organisms' behaviour, physiology, genetic and immunochemical characteristics. Thus, a well-balanced research program on control and mitigation requires as a point of departure, information about these factors.
>
> "From this base of information acquired under the biology/life history research area, the research program in control and mitigation can move into the investigation of a variety of control measures: engineering (redesign of water-intake pipes, etc.); physical (scraping, filtering, etc.); biological (parasites, predators, etc.); and physico-chemical (heat, pH, etc.). These lines of investigation should be paralleled and include both short-term and long-term means of control and mitigation of nonindigenous species. Finally, control of nonindigenous species must be ecologically acceptable and responsible. In particular, research on proposed biocides would include consideration of their toxicity to other organisms, persistence in the environment, and bioaccumulation.

Ecosystem Effects of Nonindigenous Species

> "Any new organism introduced to an existing ecosystem has the potential to alter or disrupt existing ecosystem relationships and environmental processes. The implications of a nonindigenous species invasion of an ecosystem, especially in relation to competition for food with other species ranging from zooplankton and benthos to juvenile fish, may be far-reaching. The invasion of nonindigenous species can significantly affect the populations of other organisms that are important components of the existing food web, ultimately leading to either overpopulation or demise of important existing species. In addition, some nonindigenous organisms can influence, and possibly significantly change, environmental processes that determine water quality, such as the distribution and cycling of particulates and toxic contaminants, and the productivity of the affected water bodies.
>
> "Therefore, a high priority of any nonindigenous species research program must be to identify and evaluate the likely ecosystem and environmental effects and changes that the new organisms, at each stage of its life history, is likely to produce. Such information will assist natural resource managers in making decisions that will minimize, and/or accommodate as much as practical, the ecological and environmental impacts that invading organisms have on established biota and their habitats.

Prevention of Introduction of Nonindigenous Species

> "Once introduced and established in an open aquatic system, nonindigenous species have proven impossible to eliminate. While effective means may be found to control these organisms at some ecological or socio-economic level of acceptance, in most cases little can be done to minimize ecosystem impacts and resulting resource losses. Emphasis, therefore, should be placed on preventing the introduction of new nonindigenous species into the system.
>
> "First, the potential means of introduction must be identified. Then, research should focus on establishing cost-effective, realistic methods of prevention. For example, ballast water discharge is an important vector for nonindigenous species introduction in the Great Lakes. Strategies must be developed to effectively eliminate this source of introduction without imposing undue hardships on the shipping industry. Strategies to eliminate other means of nonindigenous species introductions, such as intentional release, opening of

canals, accidental release, and so on must be examined in a similar fashion.

"In addition, not all introduced species become widespread and abundant. An examination of life history characteristics and past dispersal patterns in other aquatic environments worldwide can identify those species most likely to spread into and colonize the Great Lakes.

Reducing the Spread/Distribution of Nonindigenous Species

"The scientific ability to predict the spread of an established nonindigenous species (that is, a viable reproducing population) is dependent on knowledge of the species' environmental requirements and its dispersal mechanisms, which allow it to reach new areas where environmental conditions are favourable for growth and reproduction. Most nonindigenous species have been introduced and spread by anthropogenic activities (ship ballast, boats, the pet industry, and so on). However, the mechanisms by which dispersal occurs are often unique to each species and are usually discovered once geographic range extensions have already occurred.

"Basic understanding of nonindigenous species biology and documentation of past modes of dispersal can be used to establish likely future dispersal mechanisms. Once dispersal mechanisms are identified for individual established nonindigenous species, proper safeguards and international protocols can be developed to prevent and/or slow the spread to uninfested areas. Such safeguards and protocols may also be applicable to preventing the spread of new, not-yet-established nonindigenous species. Analysis and identification of past and possible future dispersal mechanisms of nonindigenous species will enhance the ability to control and mitigate the impact these species may have on the ecosystem.

Socio-economic Research Costs and Benefits of Nonindigenous Species

"Natural resource managers need to be aware of the potential effects of nonindigenous species on the economy and society so that they can adjust their management strategies to control and direct the impacts. Experience with most nonindigenous species indicates that negative impacts usually predominate over positive ones; nonetheless, research should address both aspects for the benefit of society. Research should focus on the potential impacts on human health in terms of spread of disease, concentrations of pollutants, and contamination or purification of drinking water sources. Economic impact investigations should broadly examine effects on all productive uses of aquatic resources including the sport, commercial and tribal fishing industry; the recreation and tourism industry; shipping and navigation needs; and municipal and industrial water users. Economic uses of nonindigenous species, for example as food for domestic animals or fertilizer for gardens and crops, should be evaluated. Finally, research results should be used to provide a scientific basis for developing sound policy and environmental law and for education and technology transfer on socio-economic effects."

The rank order of these six foci by the participants, from their particular perspective, was:

1) prevention of introduction
2) socio-economic considerations and analysis
3) control and mitigation
4) ecosystem effects
5) spread of established zebra mussels, and
6) biology and life history.

Each of these six research foci comprises a series of sub-elements and the workshop participants selected and ranked these and prepared the following statements of the recommended research priorities for zebra mussels in Lake Erie and for the introduction of other exotic species, from their perspective.

According to the *Ecophilosophers*, the new focus can be organized into a network with three equally important or complimentary nodes. These nodes include:

1. Direct, visible and immediate reactions for curvature and/or correction at multiple locations
2. Learning to adapt constructurally, or in adaptive environmental management (in both the medium and long term)
3. Prevention at a continental, global and long-term level.

The *Research Managers* adopted a different interpretation of the new research focus and its defined elements. They presented five basic needs to be addressed by zebra mussel research:

1. To develop protocols/policies to minimize/prevent introduction of additional exotic species
2. To assess the financial impacts of ballast controls on ocean-going ships
3. To develop protocols/policies to contain/control new established species
4. To develop long-term, integrative control strategies to keep Lake Erie zebra mussel populations under acceptable levels (to minimize the ecosystem impact)
5. To develop cost effective and environmentally benign controls using physical processes for water users.

Policymakers highlighted stakeholders and potential interest groups in their statement of research priorities. They emphasized that research priorities for zebra mussels in Lake Erie should be inclusive of preventive and mitigative approaches. Preventive approaches include the identification of potential invaders, their environmental requirements and tolerances, and the determination of preventive measures through the development of legislation and appropriate technology, particularly related to shipping and navigation. After an invasion by an exotic species, mitigative approaches become publicly mandated. Predictive models should then be developed to establish effects on nutrient and contaminant cycling, integrated control strategies through understanding of the consequences of the various control options, and the development of physical rather than chemical control measures.

The *Social Scientists* adopted a broader view in their statement of research priorities. Fearful of excluding the other research foci by proposing a single integrated focus, they presented a generalized approach to the zebra mussel research priority problem. They stated that research priorities can be identified by using the six previously defined research foci and ranking elements produced during the framework exercise. This approach should be an iterative process that can be used to identify specific research projects as needed.

The *Stakeholder* perspective emphasized their interests and viewpoints to ensure that their concerns are not ignored or forgotten in the priority establishment process. Rather than preparing a statement of research priorities, they commented on a number of the most highly valued elements. Stakeholders gave a low ranking to the issue of nutrient and contaminant cycles because they are unimportant unless the zebra mussel manifests itself in algae blooms or reduced water clarity. The identification of potential invaders received a medium priority ranking. The remaining elements were rated highly for a variety of reasons. Shipping and navigation should be a high priority because they have already been substantially impacted and further costs should be avoided. Determination of preventive measures is important because stakeholders are not prepared for future unexpected events. Physical measures are of high priority to stakeholders because they are non-chemical and may provide alternatives to the disruption of non-targets. Finally, stakeholders were highly concerned about the consequences of control. They call for an evaluation of trade-offs between the minor consequences of immediate action versus the long-term damage of no action.

Other than the social scientists who adopted a much broader interpretation of the establishment of research priorities, the perspective groups accepted the new research focus as a means of setting research priorities for zebra mussel research in Lake Erie. Although each perspective presented the new focus and ranked elements according to their particular interests, a consensus was adopted on the process used to determine priorities and the content of the newly favoured research focus.

3.2.2 Wetlands

The International Joint Commission, in assigning priorities to the Council of Great Lakes Research Managers, determined that there should be a workplan element on wetlands as part of the priority on "Impacts of Changes on the Lake Erie Ecosystem." The Commission noted that approximately two-thirds of the original wetland areas of the Great Lakes basin have been destroyed, and that wetlands play an important role in maintaining healthy fish and wildlife populations and desirable water quality and quantity. The most recent report on the State of the Lakes noted that, notwithstanding the efforts of individual agencies over several decades, in some cases, to delineate these wetlands, a common comprehensive binational map has yet to be developed. Thus the extent of basinwide wetland loss can only be implied through anecdotal evidence.

Identification and preservation of wetlands is mentioned twice in the Great Lakes Water Quality Agreement. Annex 13 of the Agreement is concerned with pollution from nonpoint sources and section 3 of the annex states that significant wetland areas in the Great Lakes system that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated. Similarly, Annex 17 of the Agreement states that the Parties shall determine the aquatic effects of varying lake levels in relation to pollution sources, particularly respecting the conservation of wetlands and the fate and effects of pollutants in the Great Lakes Basin Ecosystem in accordance with Annexes 2, 11, 12, 13, 15 and 16. These two references provide the context for the involvement of the International Joint Commission in the evaluation of the technology for surveillance of the status of wetlands.

As explained elsewhere in this report, this wetland priority was included for consideration in the design of the Lake Erie model. The following report describes some of the recent advances in research and development, particularly the remote-sensing technology being applied to survey wetland habitat in the Great Lakes basin, with particular reference to studies that have been undertaken on the extensive wetlands in the delta of Lake St. Clair. Staff of the Great Lakes Regional Office of the International Joint Commission worked in collaboration with scientists and technologists from the Remote Sensing Satellite Ground Station of the Chinese Academy of Sciences in Beijing, the Canada Centre for Remote Sensing, and Intera Information Technologies in Ottawa, and the Department of Geography of the University of Windsor (Li et al. 1995).

The two systems that were compared were both satellite mounted. One of the systems is the Landsat Thematic Mapper which senses seven bands at optical and infrared wavelengths. The second system is the Synthetic Aperture Radar, which is operational through cloud cover and thus can theoretically be used in all weather, was carried on the Earth Resources Satellite-1. Data from these two systems are received in a digital format. Because the Thematic Mapper, as a passive receiver, cannot operate through cloud cover, data from the weather reporting station at Wallaceburg were obtained to assist in the selection of the specific dates, between May 1992 to April 1993, on which the satellite data were obtained. Two sets of data were acquired for the Thematic Mapper, using three wavelengths. Ten sets of data were used from the Synthetic Aperture Radar.

The following seven classes of land cover were identified in the delta of Lake St. Clair, from topographic maps and aerial photographs: urban; forest; agriculture; cattail marsh; phragmites wetland; swamp; and open water. Seven areas, representing each of these classes, were chosen for calibration of the radar data and comparison with the data from the optical sensors. These data comparisons from the two different systems were made using data for locations that had been verified precisely to be the same. The ten sets of radar data were analyzed using principal component analysis to display the information as a single channel for machine classification or the interpretation of images. Prints of the images generated from these various kinds of data processing were used for laboratory analysis and to compare with the actual land cover observed during field visits.

The results showed that both systems are reliable bases for classifying land cover in the delta of Lake St. Clair, and the two data sets were better than either alone. Best results were obtained when weather conditions were warm and dry and during the season of active plant growth. With the radar system the response over agricultural land was influenced by whether or not there was a crop and whether the bare ground was dry or wet. Images from radar data collected in March for urban and forest areas, and in June of phragmites grass and cattails, could not be distinguished. The resolution of the various categories of land cover is poor under freezing weather conditions and decreased with rain, and the separation of the boundary between the vegetation and the water is obscured under windy conditions.

Figure 3.
Satellite Mounted Remote Sensing System Results — Composite Image of St. Clair River Delta and Lake St. Clair from Satellite (ERS-1) Remote Sensing

Source: Canada Centre for Remote Sensing, Geomatics Canada, Ottawa, Ontario

The use of satellite-mounted remote sensing has proven to be a reliable system for classifying land use for almost two decades. Data from the system best distinguishes the various classes in the spring. For example, swamp and phragmites marshes have similar images in the fall but can be reliably distinguished in June. The best results were obtained using two wavelengths of the optical system combined with the radar data after it had been transformed, using principal component analysis and printing of the image in a false colour composite as shown in Figure 3. There are several advantages to the application of this technology. First, it can be used to integrate data using common criteria across jurisdictional boundaries. Second, it is capable of using different resolutions to yield comprehensive or selective coverage on a geographic or temporal basis. Finally, it provides the ability to respond in a relatively short time period. The project has demonstrated that this technology could be used by the Parties to the Great Lakes Water Quality Agreement and jurisdictions in a common binational evaluation of the status of wetlands and other land uses in the Great Lakes basin.

3.3 VISION WORKSHOP

The Council of Great Lakes Research Managers held a vision workshop on February 21 and 22, 1995 in Windsor, Ontario to review progress on the Council's agenda, which had been developed at a previous vision workshop held in Niagara-on-the-Lake in 1989, and to develop a new agenda for the period 1995-2000.

Workshop participants reviewed some of the achievements of the Council since the 1989 workshop. The Council was instrumental in focussing the attention of the Parties, and the International Joint Commission, on the need to investigate the implications of the introduction of zebra mussels and quagga mussels into the Lake Erie ecosystem. The Council has developed an Ecosystem Framework to link research on natural systems to the socio-economic and political systems, and applied this framework to the ranking research priorities and policy options concerning the introduction of exotic species generally and zebra mussels in particular.

The Council published a Research Inventory in 1990-91 and 1991-92 that detailed the research undertaken to investigate the Great Lakes and prepared a report on indicators of ecosystem integrity, which was published in 1991.

At the February 1995 Vision Workshop, the Council reviewed its Terms of Reference. It recommended that the terms should be broadened to promote communication, co-operation, collaboration and coordination between researchers and agencies, and encourage the review and integration of research results and their transfer to policymakers, resource managers and the public.

The Council members identified the following five priority areas for future action planning by the Council:

Communications and Education

The responsibility of scientists to inform and involve our citizenry about their work and results is paramount, particularly when there are serious ethical dilemmas which need to be resolved. Given this backdrop, areas where scientists cannot agree could be identified, with the implications for the future as a basis for informed public debate. There is a clear role for the Council in leading the identification, development and promotion of common protocols and standards for conducting research between the various jurisdictions. Meetings of the Council could be used to share priorities and program results with members and public interest groups. The addition of socio-economic disciplines to its membership would enhance the ability of the Council to deliberate in a multidisciplinary and perhaps interdisciplinary manner. Operationalizing the Ecosystem Framework would go a long way toward implementing Council's communications and education priority.

Evolving Trends

Reiteration of the need to focus on research that ensures compliance with the Great Lakes Water Quality Agreement and the 14 use impairments is stressed. In particular, the effects of the following four trends on determining the Great Lakes research agenda need consideration: the effect on the professional development of Great Lakes research scientists as a result of U.S. federal policy to use inhouse researchers; the effect of the U.S. federal trend to shift activities toward the states, and the local level may result in a narrowing of focus away from basinwide research; the weight given to the use of risk assessment and public interest group agendas in determining research priorities; and the magnitude of the threat of endocrine disrupting compounds.

Organizational Issues

The promotion of collaborative interjurisdictional and interdisciplinary research planning is considered to be of paramount importance. Pooling of talent and resources of the Council's member organizations as a collaborative model and learning experience could identify ways of overcoming existing barriers to achieving this goal.

Research Review

Over the next five to ten years, the review function of the Council is expected to expand considerably. This is partly due to the broad research scope involved in implementing sustainable development and ecosystem management practices. When coupled with the continued limiting of human resources and research funds, the Council envisages that a direct benefit will be realized when selecting new research activities and when planning for the continuation of projects. The Council identifies the need for a blend of strategic, basic, priority and applied research in fulfilling the mandate in Annex 17. The continued assessment of the effectiveness and impact of research is expected to become more and more necessary. A strategy to identify criteria that will determine what is reviewed will be necessary.

Sustainable Development

Sustainable development as a concept will need to be translated into actionable research programs. To address this gap, the Council needs to facilitate the assessment of research to determine its relevance to sustainable development. A major contribution of the Council could be to develop a "Sustainable Development Roadmap." An examination of the Parties' role in sustainable development, emphasizing research aspects of certain selected projects such as the Lake Superior Binational Program, the Hamilton Harbour and Remedial Action Plans would assist in implementing this widely embraced concept. Identifying links between sustainable development in the application of the ecosystem approach would be a substantial contribution to research managers. The Council is committed to incorporating the priority of sustainable development into the four key areas of the Council's work, namely: Communications and Education, Organizational Issues, Evolving Trends and Review.

Results of the Council's deliberations were organized by objective, in order of priority. The following section identifies the actions to be undertaken by the Council, subject to Commission approval, arranged in relation to its terms of reference, with proposed features in italics. Collectively, they make up what the Council has termed "Achievements 2000: The Council's Vision.

Objective #1: Promote communications, cooperation, collaboration and coordination between researchers, agencies and Parties in addressing IJC priorities. Specifically the Council will encourage the promotion of interjurisdictional and interdisciplinary planning and coordination of research related to the implementation of the GLWQA.

Action 1:	Dissemination of research results to public and educators
Action 2:	Improve effectiveness of research coordination
Action 3:	Lake Erie Ecosystem Model - Phase 2
Action 4:	Operationalize the Ecosystem Frame work
Action 5:	Presentations on priority research issues at Council meetings
Action 6:	Improve communications within the Council and the research community
Action 7:	Review Council membership

Objective #2: Encourage preparation and dissemination of syntheses of research findings to government and nongovernment bodies concerned with Great Lakes management *through the systematic reporting of results through common planning and reporting mechanisms*; and bring policy implications of the aforementioned findings to the attention of the recipients.

Action 1:	Foster mechanisms to synthesize research data sets to assess long-term trends in the Great Lakes (e.g. persistent toxic substances)
Action 2:	Establish a Home Page on the Great Lakes Information Network and World Wide Web
Action 3:	Create opportunities for public input to the research agenda and priorities
Action 4:	Foster methods to develop data standards and protocols, to achieve standardized data sets for specific initiatives.

Objective #3: Compile and summarize current and planned research programs related to the implementation of the GLWQA; *assess the adequacy of the Parties research programs relating to the GLWQA and Annex 17; and promote the transfer of research findings to basin policymakers, resource managers and the public.*

Action 1:	Assess the research inventory to identify its usefulness and the potential willingness of users to pay for the inventory
Action 2:	Subject to action 1, update and maintain the inventory, publish the inventory on GLIN and produce printed version
Action 3:	Assess, analyze and evaluate research programs, recommend steps to fulfil unaddressed mandates

Objective #4: Identify research needs; establish priorities and *identify gaps and* encourage the Parties to make the maximum effort to shift funding towards directly relevant studies to the GLWQA's purpose.

Action 1:	Establish a formal process and strategy to identify top research priorities
Action 2:	Develop a white paper and conduct a workshop on Sentinel Event Reporting
Action 3:	Develop a white paper and conduct a workshop to assess factors used by the Parties in establishing research agenda (with particular focus on the role of risk assessments and public interest groups)
Action 4:	Develop a strategy for Council review of ongoing research to determine if ecosystem approach and sustainable development goals are being achieved

Objective #5: Keep under review the impact of research recommendations made by itself, the Great Lakes Science Advisory Board, the Great Lakes Water Quality Board and the Commission.

Action 1: Establish Evolving Trends Subcommittee of the Council and liaise with the Science Advisory Board's Workgroup on Emerging Issues

Conclusions

As the Great Lakes research community moves towards the year 2000, continued care needs to be taken to ensure that the limited resources are directed towards scientific and management priorities.

The aspirations of our individual members are reflected in the Council's ongoing commitment to ensuring the continued improvement of the health of the waters and ecosystem of the Great Lakes basin. Our action plan is pragmatic and cost effective and will ensure the progress continues to be made in understanding the Great Lakes system so that important management decisions can be made.

"Achievements 2000: The Council's Vision" is optimistic, even in these uncertain times. We recognize the importance of the ecosystem approach to Great Lakes management, thus the "framework" which we developed. However, we reiterate and emphasize the importance of pursuing substantive research actions to understand, document and effect the virtual elimination of priority persistent toxic substances. Our progress towards achieving sustainable development must be more clearly understood. A testament to the Council's role in this area is the work we initiated with the Lake Erie prototype model, which is a significant effort to understand the changes in the Lake Erie basin, and to influence a management framework which achieves *sustainability*.

We must take advantage of new communications technology to improve our dialogue, debates and discussion, particularly between scientists and managers. These actions are simple, yet effective.

Our review of the past five years, our Terms of Reference and our aspirations reveal our unanimous view that the Council has a fundamentally important role to play in ensuring closer integration between science, managers and public interest groups; that our research agenda is developed on a collaborative, priority basis; and that checks and balances continue to occur to ensure relevance. Our track record over the past five years is indicative of the considerable results which can be achieved through this outstanding example of bilateral, multijurisdictional collaboration.

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Chapter Four:

LAKE ERIE TASK FORCE

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PREAMBLE

The current version of the Lake Erie model is a *prototype*, intended to be as a framework for further model development, including the incorporation of additional issues of concern to Lake Erie and Great Lakes managers and researchers.

The model is not intended to be a management tool at this stage of its development. Instead, the model needs extensive testing, scoping and calibration. After these trials, the Task Force expects the model will have considerable utility in understanding and managing Lake Erie's ecosystem, and assisting in setting priorities for research. Ultimately, the model could advance management strategies for all of the Great Lakes.

The Task Force encourages reviewers to use the model to conduct tests, add data and explore hypotheses; however, the Task Force cautions using the model to develop management strategies at this stage of development.

A LETTER FROM THE CO-CHAIRS

The accompanying report describes the work conducted by the Lake Erie Task Force over the past two years. Our charge from the **International Joint Commission** (IJC) was to provide advice on the impact of the various stressors on the Lake Erie ecosystem. In traditional IJC fashion, we have worked with others from government and academia, including expert modellers and managers, who shared their time with us because of mutual concern about Lake Erie and its changing state.

The Task Force undertook its mission by seeking strong technical modelling expertise, researching to reduce the potential for duplication, and ensuring frequent interaction and consultation with key stakeholders. We believe that this combination provides the setting for a sustainable ecosystemic approach to modelling.

We convened discussion groups and workshops to benefit from expert advice from a diverse and stimulating group of managers and scientists. We harvested the ideas, intuition, knowledge and concerns of some of the best scientific and policy minds in the Great Lakes basin.

The Prototype Ecological Model was built on this advice. Numerous approaches to developing the model could have been used; after much consideration, we selected one. However, the selection is just a beginning upon which we can build a sustainable modelling process and framework, which should be valuable for years to come.

The following report describes the approach taken to develop the model, outlines the model's capabilities and scope, and recommends next steps for the International Joint Commission to consider. We look forward to continuing this work in the future.

Yours truly,

Dr. Jeffrey Reutter	Dr. Douglas Dodge
U.S. Co-Chair	Canadian Co-Chair
Lake Erie Task Force	Lake Erie Task Force

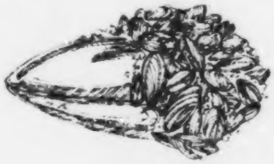
4.0 INTERNATIONAL JOINT COMMISSION CHARGE TO THE LAKE ERIE TASK FORCE

With the beginning of a new biennial cycle in October 1993, the Commissioners assigned a series of priorities and their sub-elements to various **International Joint Commission** (IJC) Boards and Committees. These included, "Ecosystem Framework" and "Wetlands," which were assigned to the Council of Great Lakes Research Managers, and "Pesticide Usage," "Groundwater," and "Pollution from Land Use Activities (PLUARG)," which were assigned to the Water Quality Board. These sub-elements are reported on elsewhere in the referenced sections.

The "Ecological Changes" sub-element, initially assigned to the Lake Erie Steering Committee, was subsequently expanded to include preparation of a prototype ecological model of Lake Erie. The committee was upgraded to Task Force status and available resources were redirected in order to achieve this goal.

In its Seventh Biennial Report in 1994, the International Joint Commission established the Lake Erie Steering Committee, later to become the Lake Erie Task Force. This Task Force was formed as a result of a priority identified by the Council of Great Lakes Research Managers. As facilitators and catalysts for Great Lakes research, the Council had identified the need for a comprehensive understanding of the changes in the Lake Erie ecosystem. The purpose of the Task Force was to provide advice to the Commission on the impact of various stressors affecting the health of the Lake Erie basin. In particular, the Task Force was to focus its efforts on the negative effects of stressors on the Lake Erie benthic and fish communities, and report to the IJC at its eighth Biennial Meeting on Great Lakes Water Quality.

After considerable discussions and reviewing initiatives and activities surrounding the state of Lake Erie, the Task Force determined the need to develop an ecosystem model for Lake Erie. This model would integrate current knowledge, determine linkages between stressors and ecosystem balance, and be capable of assessing and predicting potential adverse effects from nonindigenous species entering Lake Erie. Expert advice and guidance from scientists in the field were considered important before concluding on either the need for, or the purpose of, such a model.



The Task Force organized a workshop as a precursor to model development to determine the need, the scope and the boundaries such a model should take. Results from this workshop, held in June 1994, encouraged the Task Force to pursue the development of an ecosystem model for Lake Erie. Workshop participants confirmed the need for a Lake Erie model, and identified key elements of an approach to model development, including: a comprehensive inventory of existing models, focusing on their scope, linkages and data gaps; and development of a stress/response model for zebra mussels to test critical questions and linkages.

Participants recognized the benefits of the IJC taking a coordination/leadership role in a Lake Erie model development initiative, and stressed the need for involvement by those who will ultimately use the model, including Lake Erie managers in federal, state and provincial resource management and environmental control agencies, the Great Lakes Fishery Commission and others.

4.1 WHAT IS HAPPENING TO LAKE ERIE?

From a water quality perspective, the current condition of Lake Erie is a mixed success. Phosphorus loading targets are now being achieved. Reductions in phosphorus loadings, coupled with the filtering effects of zebra and quagga mussels, have resulted in impressive increases in water clarity.

By 1993, phosphorus and chlorophyll levels in the eastern and central basins were approaching oligotrophic conditions. Secchi disk readings were averaging more than 4 metres (13 feet). The lake's clarity is a cause of celebration to many lakeside residents. As an overall success story, however, this visible progress may be deceptive.

Trends which previously demonstrated a decline in contaminant body burdens in fish and wildlife now appear to be levelling off. Increasing levels of persistent, chlorinated hydrocarbons are being observed in some age groups of fish.

Ecosystem scientists report that populations of the invertebrate, *Diporeia*, have declined by 40 percent since 1965. *Gammarus* and oligochaete populations have increased dramatically while native unionid clams have almost disappeared. The changing trophic status suggests that the lake may not be able to support traditionally high fishery yields: stocks of white perch, yellow perch and smelt are rapidly declining.

From a fish productivity perspective a dramatic recovery of walleye and other fisheries was experienced throughout the 1980s. But this recovery also appears to be in decline.

Both fishery managers and fishers are expressing concern that this decline is due to further reductions in phosphorus loadings, together with the apparent impact of zebra and quagga mussels on energy flow and nutrient cycling.

Lake Erie is again front and centre in the minds of user groups and governments. In short, the celebration of success may be short-lived. As we move through the next decade, we must become better informed of the overall ecosystem dynamics, the interrelationships between stressors, and the net, overall effect those stressors have on the lake ecosystem. This understanding is crucial for the next set of management decisions about water quality and fisheries management in Lake Erie.

4.1.1 Management Questions

Great Lakes scientists and research and program managers are challenged by these changes in Lake Erie. There are more questions than answers. Not all changes in Lake Erie can be attributed to invasions of zebra and quagga mussels, nor to the significant reductions in loadings of phosphorous. Other factors may be causing the observed changes; for example, declining forage fish stocks may reflect the large number of predators feeding in the lake.

In 1994, most agencies had identified Lake Erie as a top priority. Several meetings and workshops were held to coordinate programs, but there was a growing concern that a large number of unconnected projects could not by themselves correctly diagnose the problems and lead to effective management actions.

Important gaps in knowledge were identified in the Lake Erie priority. These included:

- what is the effect of zebra/quagga mussels on energy flow?
- if phosphorus levels continue to decline, what will be the effect on fish production?
- what is the impact of contaminant cycling on the physical, biological and chemical state of the Lake Erie ecosystem?
- what role does the loss and/or change of habitat/ wetlands play in the realm of energy flow and biodiversity?
- what is the effect of groundwater and its impact on water quality?

Other pertinent questions are related to management decisions that must be made soon, to ensure better management of fisheries and water quality of the system. These include:

- what factors are causing the change in the Lake Erie ecosystem?
- how can we make informed decisions in the absence of this understanding?
- how do we balance competing resource management issues; for example, good water clarity versus fish productivity?

4.2 DEVELOPING THE MODELLING PROJECT

Building on the results of the June 1994 workshop, the Task Force began the **Lake Erie Ecological Modelling Project** (LEEMP) in January 1995. The purpose of the project was to encourage the development of an ecological model that would enhance understanding of rapid changes taking place in the Lake Erie ecosystem.

The Lake Erie Modelling Project had two main initiatives:

- a comprehensive review of existing ecological models to describe key attributes, and assess the applicability of these attributes to the development of a Lake Erie model; and,
- development of a Lake Erie prototype model to address chemical, physical and biological aspects and their linkages, and to integrate the effects of zebra and quagga mussel infestation as a stressor in Lake Erie.

A binational consulting team was organized by the LURA Group, a Toronto-based environmental planning firm, Dr. Joseph Koonce, a Great Lakes modelling expert, and Dr. Ana Locci from Case Western Reserve University in Cleveland, Ohio. At the outset of the project, the consulting team established a Core Advisory Group of Lake Erie fishery and water quality managers. The Core Advisory Group provided critical advice and guidance regarding implementation of Initiatives I and II of the LEEMP.

4.2.1 Initiative I: Review of Existing Ecological Models

Nine ecological modelling projects were reviewed to identify attributes applicable to the design and development of the LEEMP; these projects are briefly described below. For a detailed report, see the Task Force's "*Initiative I Report: Review of Existing Ecological Models, March, 1995.*" The nine models varied greatly in purpose, complexity, level of development, and the nature and amount of information available about them. They included:

1) Puget Sound Systems Model
2) Green Bay Mass Balance Study (GBMBS)
3) Sustainability of Intensively Managed Fisheries (SIMPLE) Model
4) Chesapeake Bay Ecosystem Model
5) Eutrophication Model for Louisiana Inner Shelf (Gulf of Mexico)
6) Lake Erie Information Forecasting System (LEIFS)
7) Saginaw Bay Zebra Mussel Model
8) Lake Michigan Mass Balance Project (LMMBP)
9) Network Model of Lake Ontario and Erie

These nine models were developed to study specific ecosystem functions. Some are based on the same framework or contain common subsystem models. The Puget Sound Systems Model was developed in 1975 as a tool for water quality decisionmaking. Designed to expand on the application of earlier models, it has subsequently been developed into the **Water Quality Analysis Simulation for Toxics** (WASP4) model. The WASP4 model framework provides the basis for several current models, including the GBMBS and the Eutrophication Model for the Louisiana Inner Shelf (Gulf of Mexico), numbers 2 and 5 above, respectively.

GBMBS relates loadings of nutrients, solids and contaminants with concentrations in the water column and sediments. The WASP4 framework is a linked submodel approach which combines two parts: exposure concentration (physical-chemical) and food chain components (U.S. EPA 1989). The goal is to be able to predict concentrations in water, sediment and biota in response to differing regulatory and remedial action scenarios.

The Eutrophication Model for the Louisiana Inner Shelf (Gulf of Mexico) uses a **Limno-Tech, Inc.** (LTI) modified version of the **U.S. Environmental Protection Agency** (U.S. EPA) WASP4/EUTRO4 model. The scope of this model is limited to considering primary production. The model was used to estimate responses of primary productivity and dissolved oxygen to reductions in nutrient loadings from the Mississippi and Atchafalaya Rivers.

The Lake Michigan Mass Balance Model, in the development stages, proposes to apply the same linked submodel approach used in Green Bay. The mass balance model for toxics in Lake Michigan will retain some of the same basic models as the GBMBS. The model will be comprised of linked hydrodynamics, eutrophication/sorbent dynamics, particle transport, contaminant transport and transformation, and bioaccumulation simulations.

The Saginaw Bay Zebra Mussels Model represents the lower food web, including zebra mussels, within a mass balance modelling framework. It is based on the original multi-class phytoplankton model used to establish the target phosphorus loading for Saginaw Bay as part of the 1978 Great Lakes Water Quality Agreement. The phytoplankton-zebra mussel model is a research tool and has not, as yet, been used by any management agencies.

The LEIFS Model is part of the **Great Lakes Forecasting System** (GLFS), which makes six-hour forecasts for currents, temperatures, wind waves, water levels and associated physical data. The model is easily accessed by modem or internet for enhancement of commercial and recreational activities, resource management and hazard avoidance.

The Chesapeake Bay Ecosystem Model addresses the flow of energy, nitrogen and phosphorus through the ecosystem. The model illustrates seasonal dynamics of the Chesapeake Bay ecosystem by providing information on the rates of energy transfer between the trophic components.

The SIMPLE Model, as applied in Lake Michigan and Lake Ontario, is a decisionmaking tool for fisheries management, which includes economic and social inputs.

The Network Model of Lake Ontario and Erie is similar to the prototype ecological model being developed by the Lake Erie Task Force. This network model is in early stages of development; one primary function is to forecast potential fish production for fisheries managers. This network approach to modelling should create linkages between a variety of subsystem models, one of which is the SIMPLE model. The network model is proposed to be developed for Lake Ontario first, and later adapted to Lake Erie. Due to its early state of development, details of the model's functions are yet to be determined.

All the models currently in use are in the public domain, but most require a degree of training for their use. The Chesapeake Bay Ecosystem Model is fully documented, including data requirements, a bibliography, operating instructions and guides to interpret data. The LEIFS model provides for public access to updated and historical files by modem or internet on the Great Lakes Forecasting System database at Ohio State. Two-dimensional maps can be displayed on the computer. The GBMBS represents the other extreme; there has been little documentation, and operation of the model requires extensive training or modelling experience.

While work is ongoing on many of these models, two models have potential to contribute to the present focus on Lake Erie: the Network Model of Lakes Ontario and Erie, and the Lake Erie Trophic Transfer Model. The Network Model, originally only for Lake Ontario, is designed to aid fisheries managers to predict fish productivity. The contractor was unable to use any attributes from the Lake Erie Trophic Transfer model given the timeframe for this project.

From this review, the SIMPLE model provided the most comprehensive approach to developing the sustainable fishery component of the ecosystem model. In addition, this model has sufficient structural scope to accommodate issues associated with nutrients, contaminants and exotic species. This model subsequently formed the core of the LEEMP.

4.2.2. Initiative II: Profile of the Lake Erie Prototype Ecological Model

Prototype Components

The prototype has six main integrated and interacting components:

1) phosphorus loading
2) contaminant loading, including
    - PCB
    - mercury
    - DDT
    - atrazine
3) zebra mussels
4) zooplankton
5) zoobenthos
6) fish community, including
    - walleye
    - white bass
    - gizzard shad
    - whitefish
    - shiners
    - smelt
    - drum
    - alewife
    - lake trout
    - burbot
    - white perch
    - yellow perch
    - smallmouth bass
    - rainbow trout

The prototype is a simplified representation of the food web of the Lake Erie ecosystem. The model simulates energy flow and contaminant movement by implementing a set of rules, which approximate the feeding behaviour of individual animals (Figure 1). Primary production depends on phosphorus loading in the model, and nutrient loading thus limits the overall productivity of the simulated Lake Erie ecosystem.

The key assumptions made in developing the prototype are included in Appendix A.

Use of Existing Models in Prototype Development

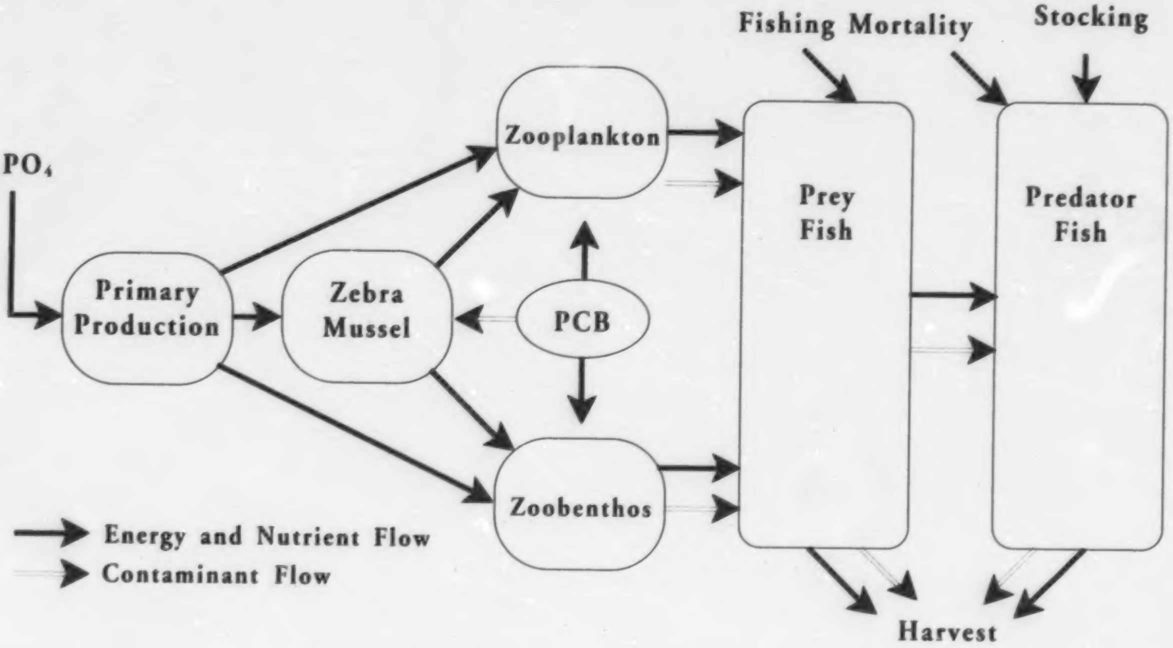
The Lake Erie prototype incorporates elements of the following existing models:

- **Sustainability of Intensively Managed Fisheries (SIMPLE) Model, Great Lakes Fishery Commission (Koonce and Jones, 1994)**. This model provided the basic framework for the scope of the prototype as well as some parameter values.

- **Lake Erie Fish Community Model (Koonce et al. 1983; Locci-Hernandez 1988), sponsored by the Great Lakes Fishery Commission and the Ohio Sea Grant Program**. This set of models provided some model structure and parameter values.

- **Individual Based Models of Contaminant Bioaccumulation (Madenjian et al. 1993)**. This model provided the modelling approach and parameter values for incorporation of contaminants into the prototype.

Figure 1.
Lake Erie Ecological Model: Energy, Nutrient and Contaminant Flows



Use of the Lake Erie Prototype

In developing its model, the Task Force had the benefit of previous work by Dr. Koonce and Dr. Locci at Case Western Reserve University. The prototype is not intended to be a management tool at this stage of development. Rather it is a heuristic[1] demonstration model which requires extensive calibration and testing. Although advice from the Core Advisory Group advanced prototype development to the point where it is nearly a useable tool, substantial work remains to make it a realistic representation of the Lake Erie ecosystem.

However, it is possible to show how the prototype might be used in discussions about some important ecosystem interactions in Lake Erie. The prototype has been designed to allow exploration of hypotheses or management actions in comparison to historical trends. The prototype begins a simulation in 1960 and runs through 1995. Two sample applications illustrate ways the model can be used:

1) A water quality manager can explore the possible effects of a 25% reduction in phosphorus loading targets for Lake Erie on harvest levels of fish, abundance trends, and other measurements, and compare these results to simulations of the actual history of changing phosphorus loading

2) A fish manager can determine how much reduction of fish harvests will be necessary to preserve important fish stocks under conditions of declining lake productivity due to the combined effects of reductions in nutrient loading and sea lamprey invasion. The manager can explore the magnitude of the adjustment to fishing mortality that may be required.

Through similarly derived scenarios, the user can explore the interactions of the various model components:

- interaction of changing phosphorus loading and fish harvesting
- effects of zebra mussel invasion on fish harvests through alteration of energy flow through the lower trophic web
- effects of changing productivity and energy flow on patterns of contaminant bioaccumulation.

Exploring these interactions is a heuristic exercise. Using the model to track complex interactions allows users the opportunity to try alternative hypotheses, or to check for consistency with other observations or models. This gaming with simulation may be the main application of a model of the Lake Erie ecosystem, and the prototype provides an example of this utility.

The prototype was tested in April 1995 when the Task Force hosted an interactive demonstration workshop for managers, scientists and researchers. Recommendations were made for a series of next steps in model development, which are included in this report.

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[1] *Oxford Dictionary* definition of heuristic — serving or helping to find out or discover; proceeding by trial and error.

4.3 EARLY OBSERVATIONS

From this project to develop a Lake Erie ecosystem model, and the subsequent review of the prototype by Lake Erie managers, scientists and researchers, the Task Force proposes a number of key areas for consideration by the IJC. **First, the model is only a prototype and needs further work by testing, trials, demonstrations and experiments.** However, a solid groundwork has been established for a long-term sustainable process to model the Lake Erie ecosystem.

At this early stage in its development, the model focuses on sustaining fish productivity as an ecosystem component and, as such, is not truly representative of the Lake Erie ecosystem. Differing approaches are being considered to ensure that the model becomes as reflective of the lake ecosystem as possible. When the Lake Erie Lakewide Management Plan Ecosystem objectives have been confirmed, these can be reviewed in the context of the model.

The model is designed to provide information based on a "whole lake" approach. There is considerable interest in disaggregating the model into three basin components, including nearshore and offshore effects. The benefits of this approach need to be evaluated.

Users may benefit from the model if it concentrates on the lower trophic levels, in sub-basin units. For example, a better link is needed between phosphorous loadings and phytoplankton and zooplankton production. These subcomponents, when developed, could connect to the lakewide model. This exercise should not proceed simultaneously with the main model development. It is important that the iterative correction process occur with the main model to determine errors prior to embarking on additional major sub-basin modelling exercises.

A number of hypothetical tests need to be conducted on the model to ensure its representativeness. Reviewers and participants in the Task Force process indicated a strong desire to run trials with the model to test certain hypotheses. The Task Force strongly supports this iterative correction process.

The Lake Erie Ecosystem Modelling Project could provide valuable insight into the challenges facing managers of the Lake Erie ecosystem. For the model to be useful, users must have confidence that it is kept up to date, and corrected as new information develops. As well, the model provides the basis for sharing information, knowledge and for developing common policy. Finally, the model provides another way for the IJC to assess progress of the Parties toward meeting the commitments of the Great Lake Water Quality Agreement.

Managers and modellers indicated a strong interest to continue involvement in model development. It is important that common goals are established among users of this model. So far, advice and input of more than 50 key advisors assisted the Task Force in developing this prototype.

4.4 RECOMMENDATIONS

The Lake Erie Task Force concludes that the model has the potential to be a valuable tool for use by Lake Erie managers, scientists and researchers, and has the potential to be adapted for use on other Great Lakes.

This modelling exercise reflects the considerable leadership of the Commission in moving towards an understanding of changes to the Lake Erie ecosystem. By starting the development of an ecosystem model, changes can be better understood and even predicted, and thus, managers can move forward with a higher degree of confidence.

Through the establishment of a special Task Force on Lake Erie, the IJC has indicated that the Lake Erie priority is of significant importance. By initiating the development of this prototype, the IJC is facilitating progress. We suggest that the IJC continue in this leadership role.

The Task Force recommends that the IJC continue efforts to develop the model through the next biennial cycle.

A series of next steps has been developed by the Task Force for consideration by the IJC. These are described below, and are drawn from the results of the workshop held in April 1995.

Step 1: Use a "Capacity Building" Approach in Developing the Model

Numerous user groups have an identified interest in the model. Users include government agencies, academia, the fishing industry, public interest groups and members of the general public. If the model is to be a useable, sustainable tool for managers over the long term, the IJC should consider attracting partners to assist with model development. This approach would ensure that an integrated, collaborative approach continues, while stretching available financial resources. To ensure continuance of management style, we recommend that the IJC remain the lead partner.

Step 2: Communicate the Model Capabilities

A guidebook to using the Lake Erie Ecosystem Model would assist users and partners to understand the basis for the model, the type of data used and include a sample log book in which to record results of tests. In identifying key attributes of other models, we discovered that, while the models may be in the public domain, few are thoroughly described and documented, such that any user can test them.

Step 3: Start an Iterative Correction Process

An iterative correction process for the model is the necessary first step to identify weaknesses in the prototype. The prototype must be adjusted and improved through a data review/trials process. The Core Advisory Group and other experts would be asked to participate in the exercise. Areas for exploration, investigation and discovery have been identified. Since the model's debut in April 1995, several modellers and managers have used the model to test assumptions. These efforts will be coordinated to ensure that results are documented and improvements are made.

Step 4: Consult with Users

There are three potential purposes for the model: a management tool; an aid to setting research priorities; and an aid in the understanding of Lake Erie ecosystem linkages. There may be a set of phased-use objectives — i.e., short-term use, mid-term use and long-term use, which could be developed based on expectations and needs of partners.

It is important to clarify the purpose and objectives of the model with potential users. An understanding of (and consensus on) its purpose(s) are desirable among key potential user groups. As was done in the initial phase of model development, consultation with managers and technical experts should continue as this model develops (i.e., Core Advisory Group, communications, technical experts meetings, and workshops).

Step 5: Test the Three-Basin Concept

After various trials, tests, corrections and new data have been applied to the model in accordance with Step 3 (such that deficiencies have been found and hypotheses have been tested), it is important to develop the model further to disaggregate its whole lake perspective into three basins (east, central and west), and also into offshore and nearshore effects. Fish migration patterns should be reflected between basins, and an accounting for changes in nutrients and contaminants must be made between basins. Seasonal variations within basins coupled with a facility to understand the effects of the thermocline on productivity and phosphorus management would also be important additions to the model.

4.5 SUMMARY

The Task Force concludes that this modelling approach has great potential as a sustainable aid in assisting Lake Erie managers to arrive at appropriate policy and management decisions. In addition, the model can identify effects of stressors on Lake Erie, in particular the fishery component. Through testing and discovery, the model structure provides for an understanding of the effects and interactions between stressors, and the linkages between stressors in the lake ecosystem. The challenge is to ensure that the modelling exercise, currently in its prototype form, continues beyond this first, rough-cut iteration. To ensure that the model becomes a useable tool should be the next step.

The Task Force has described a process which, if followed, will ensure continuance. With the collaboration of advisors, the identification of a few additional "leaders," we can better use limited resources. This approach is one previously identified by the Council of Great Lakes Research Managers as the challenge for the next five years. The Task Force endorses this approach. The development of the Lake Erie Ecological Modelling Project has been a positive exercise for the Task Force. We are indebted to all the advisors who participated in making this effort worthwhile.

4.6 CONSULTANTS' REPORTS TO THE TASK FORCE

Four detailed, background reports were prepared under contracts from the Lake Erie Task Force. These documents are available, on request, from the IJC Great Lakes Regional Office and include:

A) Lake Erie Modelling Pre-Workshop, Facilitators' Report (LURA Group), July 15, 1994

B) Initiative 1 Report (LURA Group)

C) Initiative 2 Report (J. Koonce)

D) Lake Erie Prototype Model Workshop, Summary Report (LURA Group), May 3, 1995

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APPENDIX A: KEY ASSUMPTIONS FOR PROTOTYPE DEVELOPMENT

Spatial and Temporal Scaling

A major simplification in the model is the choice of spatial and temporal scales for representing interactions in the Lake Erie ecosystem. The model assumes a whole-lake spatial aggregation and simulates changes in the ecosystem at a minimum of one-year intervals. This assumption means that the model is most realistic for fish populations and progressively less realistic for zebra mussels, zoobenthos and zooplankton, whose populations exhibit substantial seasonal variability. Zooplankton and zoobenthos dynamics, therefore, are simplified to steady-state approximations of mean annual abundance and productivity. Zebra and quagga mussels are treated as a single mussel type with only annual total biomass dynamics. Fish migration is assumed to average lakewide gradients in productivity, but spatial heterogeneity of fish populations is preserved through explicit consideration of habitat overlap among fish species and lower trophic level components of the ecosystem.

Primary Productivity Linked to Phosphorus Loading

Phytoplankton and other primary producers are not explicitly represented in the model. Instead, the model assumes that phosphorus loading determines lakewide primary productivity. Productivity of zooplankton and zoobenthos thus depend on phosphorus loading through primary productivity.

Contaminants Move Through the Food Chain

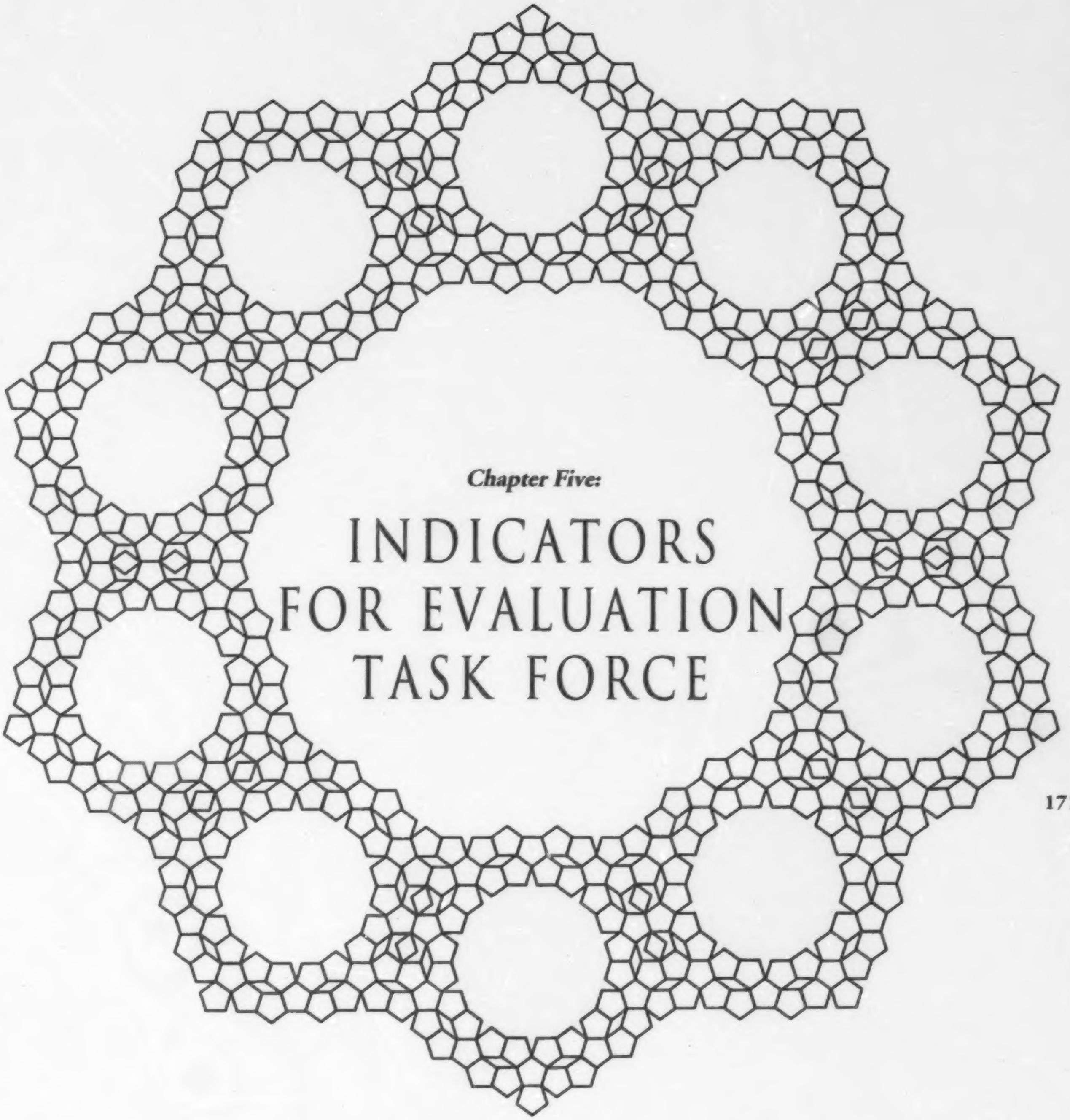
The prototype considers four contaminants: PCB, DDT, Mercury and Atrazine. Contaminant loadings and mass balances are not explicitly represented. The model assumes an input data set consisting of annual mean concentrations of each contaminant in lake water. Contaminant body burdens of organisms at lower trophic levels are predicted from estimated bioaccumulation factors, and contaminant body burdens of all other individuals depends on the annual balance of contaminant uptake (ingestion and absorption) and excretion.

Bioenergetics of Growth and Reproduction

Growth of individual fish depends on feeding according to annualized, theoretical expectations from bioenergetic models. Except for rainbow trout and lake trout, all fish species rely on natural reproduction for recruitment. Predicted reproduction depends on fecundity and fertility coefficients, which vary by species and age. Habitat limitations are imposed through coefficients affecting egg mortality.

Functional Predator and Prey Interactions

Feeding by all age groups of fish depends on a common set of rules rather than a predefined set of feeding relations. Predators are assumed to search a defined habitat volume and randomly encounter prey items. Probability of capture of a prey item depends on the ratio of prey to predator and a habitat overlap coefficient.



Chapter Five:

INDICATORS FOR EVALUATION TASK FORCE

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5.0 INDICATORS FOR EVALUATION TASK FORCE

5.1 WHITE PAPER: INDICATORS TO EVALUATE PROGRESS UNDER THE AGREEMENT

Through the Great Lakes Water Quality Agreement, the Governments of the United States and Canada are committed "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." For more than two decades, numerous programs and measures have been undertaken towards this purpose.

Under Article VII of the Agreement, the International Joint Commission is charged to evaluate Agreement progress and provide advice to governments. To fulfill its mandate, the Commission requires data and information. To assist in reviewing these requirements and to develop a framework within which to conduct its evaluation and develop advice, the Commission established, in 1993, an Indicators for Evaluation Task Force.

The Task Force held an Issues Definition Session (December 2-3, 1993) and an Indicators Workshop (October 5-6, 1994), to acquaint itself with relevant activities and to identify specific indicators to evaluate Agreement progress. It subsequently developed a draft White Paper, which was circulated (May 1995) for review to the Commission's Boards and the Council, workshop participants, and selected others. Based on the comments received, the Task Force prepared a revised, final report containing findings, conclusions and recommendations. The report has been submitted to the Commission as a separate document, to which the reader is referred.

To obtain a copy of the report, please contact the International Joint Commission, 100 Ouellette Avenue - Eighth Floor, Windsor, Ontario N9A 6T3 or P.O. Box 32869, Detroit, Michigan 48232-2869.

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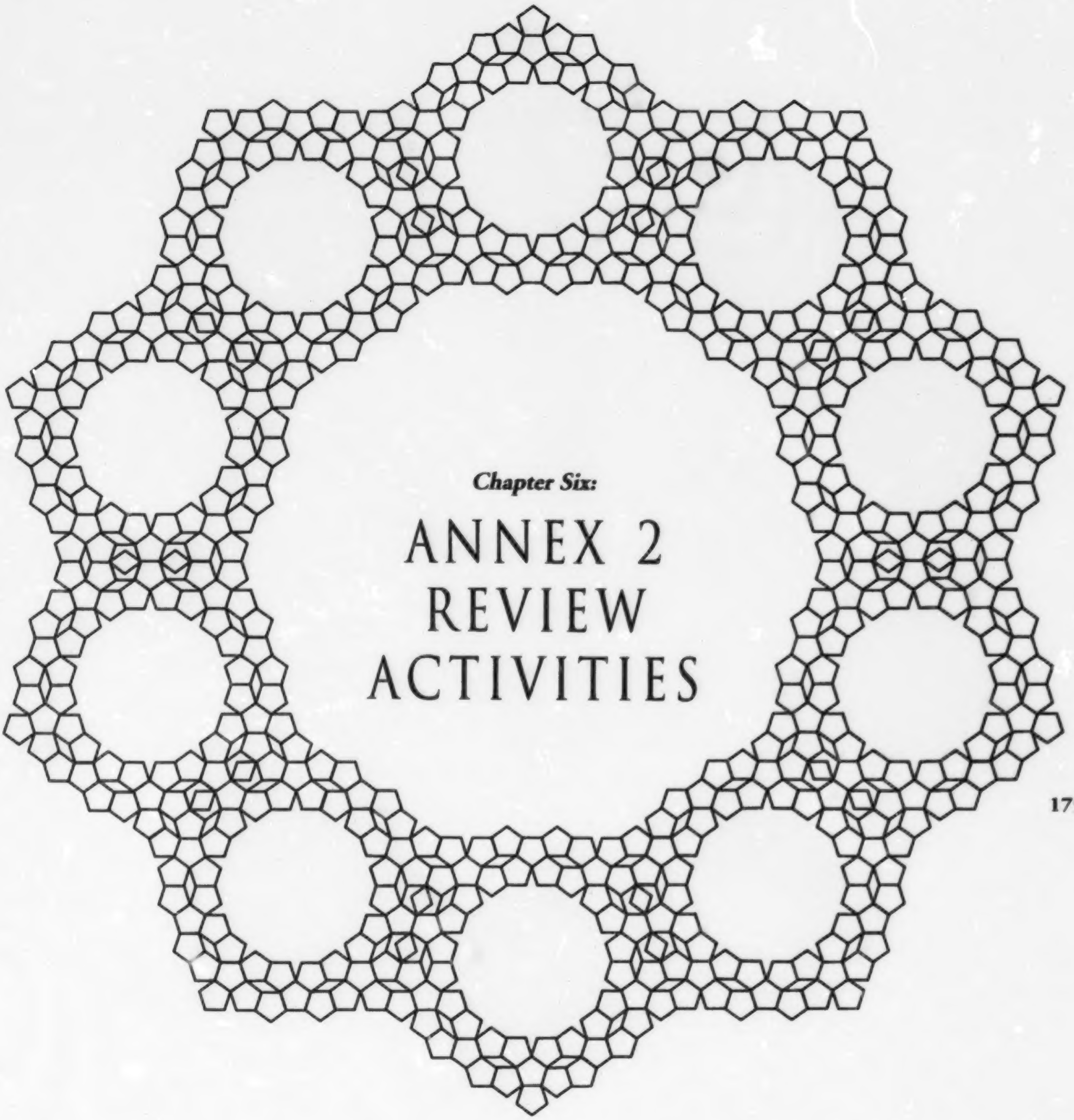

Chapter Six:

ANNEX 2 REVIEW ACTIVITIES

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Figure

1. Status of Remedial Action Plans Submitted to the IJC for the Forty-Two Areas of Concern in the Great Lakes Basin 178

6.0 ANNEX 2 REVIEW ACTIVITIES

6.1 REMEDIAL ACTION PLANS AND LAKEWIDE MANAGEMENT PLANS

"Lean and Mean Does Not a Strategy Make"

—Tom Peters

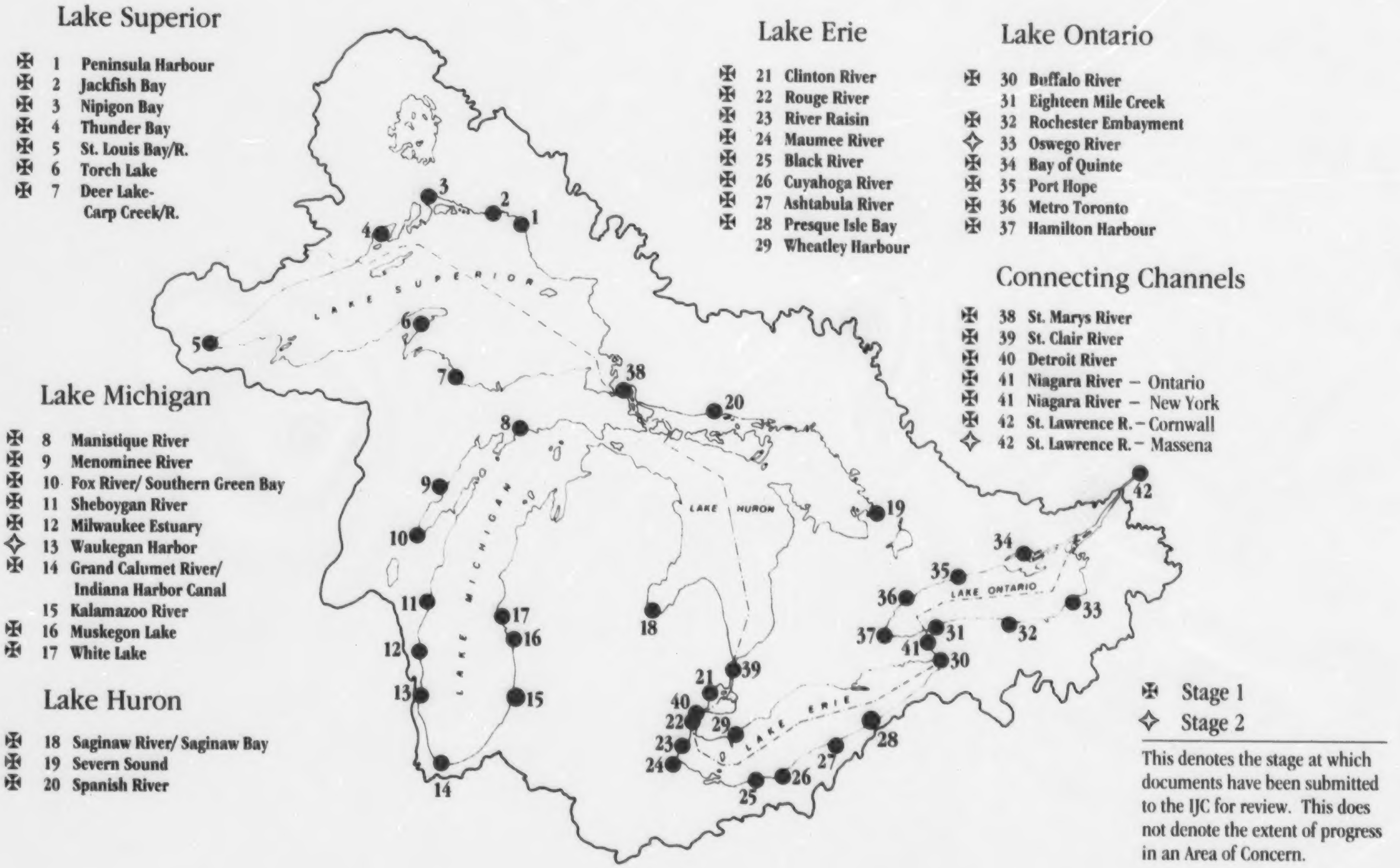
Under the **Great Lakes Water Quality Agreement** (GLWQA), as revised by Protocol in 1987, the **International Joint Commission** (Commission or IJC) provides reviews of **Remedial Action Plans** (RAPs) for each **Area of Concern** (AOC). The Commission's reviews have found that jurisdictions have done an admirable job of compiling existing environmental information and conducting studies to gather additional data necessary to describe environmental problems in their Stage 1 documents.

One former AOC, Collingwood Harbour, moved through the entire RAP process, and has since been delisted by Canada. Forty-two AOCs remain, for which three Stage 1 RAPs remain to be submitted for Commission review. This includes two separate plans being prepared on each side of the U.S. - Canadian border for the Niagara and St. Lawrence Rivers. Information regarding the status of RAP submissions to the Commission is presented in Figure 1.

The Commission's reviews have also highlighted several topics of interest. Preliminary characterization and remediation initiatives for contaminated sediments have confirmed that this is not only a major remediation challenge, but is *the* cause of impairment of beneficial uses for RAPs and **Lakewide Management Plans** (LaMPs). Notable efforts have been undertaken in both countries to quantify the extent of contaminated sediment and to identify or demonstrate options to remediate them. In Canada, the **Great Lakes 2000 Cleanup Fund** (CuF) has demonstrated 19 innovative technologies for the safe removal, handling and treatment of contaminated sediments. In the U.S., the **Assessment and Remediation of Contaminated Sediments** (ARCS) Program has conducted bench-scale testing of nine treatment technologies, four of which were then selected for pilot-scale demonstrations. These demonstrations were conducted in the Ashtabula River, Buffalo River, Grand Calumet River/Indiana Harbor Canal, Saginaw River/Bay and Sheboygan River AOCs (U.S. EPA 1994).

Because contaminated sediments influence the levels of contaminants in fish, they play a major role in human health concerns in the Great Lakes basin. Efforts have begun in both countries to better describe human health impacts in AOCs. To date, however, many RAP teams lack access to the expertise necessary to begin addressing human health concerns in their AOCs. This problem was noted in the Commission's *Seventh Biennial Report on Great Lakes Water Quality* (IJC 1994). Although much of the human health research in the Great Lakes basin, to date, has been targeted toward the consumption of fish, additional research

Figure 1.
Status of Remedial Action Plans Submitted to the International Joint Commission for the Forty-Two Areas of Concern in the Great Lakes Basin, June 20, 1995



Lake Superior

- ✠ 1 **Peninsula Harbour**
- ✠ 2 **Jackfish Bay**
- ✠ 3 **Nipigon Bay**
- ✠ 4 **Thunder Bay**
- ✠ 5 **St. Louis Bay/R.**
- ✠ 6 **Torch Lake**
- ✠ 7 **Deer Lake-Carp Creek/R.**

Lake Michigan

- ✠ 8 **Manistique River**
- ✠ 9 **Menominee River**
- ✠ 10 **Fox River/ Southern Green Bay**
- ✠ 11 **Sheboygan River**
- ✠ 12 **Milwaukee Estuary**
- ✧ 13 **Waukegan Harbor**
- ✠ 14 **Grand Calumet River/ Indiana Harbor Canal**
- 15 **Kalamazoo River**
- ✠ 16 **Muskegon Lake**
- ✠ 17 **White Lake**

Lake Huron

- ✠ 18 **Saginaw River/ Saginaw Bay**
- ✠ 19 **Severn Sound**
- ✠ 20 **Spanish River**

Lake Erie

- ✠ 21 **Clinton River**
- ✠ 22 **Rouge River**
- ✠ 23 **River Raisin**
- ✠ 24 **Maumee River**
- ✠ 25 **Black River**
- ✠ 26 **Cuyahoga River**
- ✠ 27 **Ashtabula River**
- ✠ 28 **Presque Isle Bay**
- 29 **Wheatley Harbour**

Lake Ontario

- ✠ 30 **Buffalo River**
- 31 **Eighteen Mile Creek**
- ✠ 32 **Rochester Embayment**
- ✧ 33 **Oswego River**
- ✠ 34 **Bay of Quinte**
- ✠ 35 **Port Hope**
- ✠ 36 **Metro Toronto**
- ✠ 37 **Hamilton Harbour**

Connecting Channels

- ✠ 38 **St. Marys River**
- ✠ 39 **St. Clair River**
- ✠ 40 **Detroit River**
- ✠ 41 **Niagara River** – Ontario
- ✠ 41 **Niagara River** – New York
- ✠ 42 **St. Lawrence R.** – Cornwall
- ✧ 42 **St. Lawrence R.** – Massena

✠ Stage 1
✧ Stage 2

This denotes the stage at which documents have been submitted to the IJC for review. This does not denote the extent of progress in an Area of Concern.

now underway related to other forms of exposure will provide; more data for incorporation in the RAP documents. Because much of these data will be available after Stage 2 or even Stage 3 documents have been completed, care needs to be taken to ensure that they complement existing RAPs, rather than as barriers to timely remediation.

Many jurisdictions are using some form of update to their RAP documents to capture refinements to the problem definition and to report progress as they implement remedial measures. These updates are especially valuable for providing information to the public on topics for which limited information was formerly available, such as contaminated sediment remediation options and effects of contaminants on human health.

The RAP process provides an unique opportunity for local communities to initiate actions with the assistance and support of the federal, state or provincial governments to develop programs and initiatives that solve today's problems while helping each community to achieve its goals for the future. To date, however, only a few AOCs have taken advantage of these unique opportunities. Collingwood Harbour is a prime example of a community maximizing its benefits from such an opportunity.

The Commission completed its review of the Collingwood Harbour Stage 2 and Stage 3 RAPs on August 12, 1994 and September 23, 1994, respectively, and noted several findings which may be of significance to AOCs in the Great Lakes basin. The cooperation between the RAP Team and the **Public Advisory Committee** (PAC) in the designation of use goals was notable because it provided a united front for working with the community in accomplishing its goals. The RAP Team and PAC gathered input from the general public before attempting to reach consensus on the preferred remedial measures. Pollution prevention activities, including water conservation efforts that targeted the general public in addition to the traditional targets of industrial and municipal dischargers, were also adopted in the implementation strategy for Collingwood Harbour (Collingwood Harbour Action Team 1993). Encouraging water conservation at Collingwood Harbour is an excellent example of adopting a cost-effective remedial option. The RAP Team determined that promoting water conservation could achieve a reduction in phosphorus loading from the wastewater treatment plant at a much lower cost than would upgrades to the plant. As remediation efforts are considered and initiated for expensive environmental problems such as contaminated sediments in complex AOCs such as the Lower Green Bay and Fox River, socio-economic considerations will become major factors influencing the rate and extent of remediation accomplished. Socio-economic considerations will also be vital in the virtual elimination process for certain Critical Pollutants in LaMPs.

While the ready availability of government and private support -- including financial -- at Collingwood Harbour reflect the hard work and dedication of the numerous individuals involved in the effort, their experience make apparent what will be major hurdles in the more complex AOCs, e.g. the Grand Calumet River/Indiana Harbor Canal or the Lower Green Bay and Fox River. Challenges include how to consult with a substantial portion of the concerned public, how to obtain their support for remedial activities, how to obtain financial support needed for remediation efforts and, perhaps most important, how to obtain cost-effective remediation. To place the scale of necessary efforts in proper perspective, consider that approximately 8,000 cubic meters of contaminated sediments were removed from Collingwood Harbour, while there are an estimated seven to nine million cubic meters of sediments containing more than 0.05 mg/kg polychlorinated biphenyls in the Fox River (WDNR 1993), and remedial actions for the Fox River system have been estimated at $1 billion (DePinto 1994). Obviously, potential remediation efforts of this scale require a valid framework to economically evaluate remedial options so they can be easily understood by the public. Perhaps most importantly, with decreased resources available to pay for implementation, such a framework must also provide a method to prioritize implementation efforts between selected remedial options within a AOC and even between AOCs.

These issues, while not explicitly noted in Annex 2 of the GLWQA, have been considered in some AOCs and preliminary actions are being taken. For example, in the Lower Green Bay and Fox River AOC, the Fox River Coalition made up of representatives from municipalities, industry, wastewater treatment facilities and state and local government, was formed in 1992 to develop a plan and timetable for cleanup of contaminated sediments in the Lower Fox River (WDNR 1995). The coalition has concluded that, "Contaminated sediment data available for downstream areas were too large-scale to allow identification of specific areas (for remediation)...The group maintained that it was technically and economically impractical to plan remediation for seven million cubic meters of contaminated sediment without differentiating priority areas." In fact, while the coalition maintains that the total cost of remediation of the entire river should be determined in order to finalize a funding program, local governments maintain that remediation activities should be staggered after completion of the individual projects and monitoring data, which is then used to determine the environmental benefit of each project. Prioritizing efforts and seeking funding to complete projects has been noted by the coalition: "The group recommends creation of a statewide sediment remediation program. Such a program would prioritize projects...The group will seek private and public funding at local, state and federal levels."

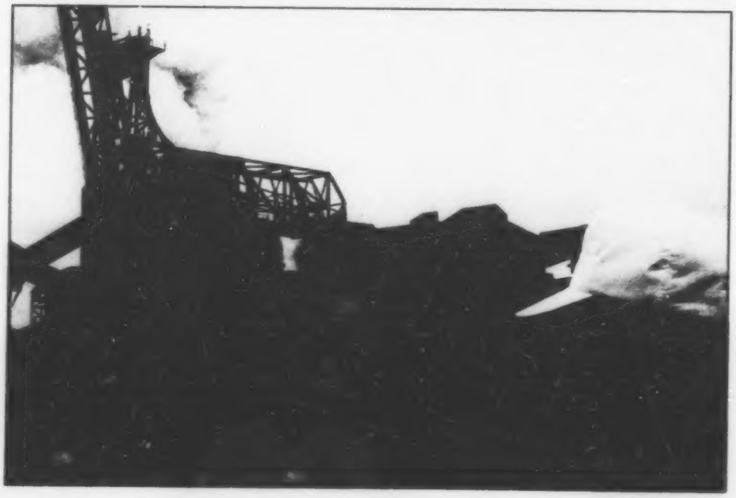
Many observations of the Fox River Coalition concerning socio-economic factors of sediment remediation coincide with Commission staff findings as a result of examining planning and implementation activities of various RAP and LaMP efforts. These findings, outlined below, are applicable to LaMPs as well as RAPs.

Numerous individuals throughout the Basin have dedicated countless hours toward remedial activities. The Commission attempts to recognize these individuals and reward their dedication. Some Areas of Concern such as the Grand Calumet River/Indiana Harbor are very complex and require innovative partnerships in order to advance remedial actions.

Commissioner Susan Bayh and former Commissioner Gordon Walker present Doug Garbutt, Mayor, Town of Collingwood with a certificate recognizing his work toward the remedial action planning process at Collingwood Harbour.

Ed Houghton, Public Advisory Committee Chairperson receiving a certificate of recognition from Commissioner Susan Bayh and Gail Krantzberg, former Coordinator of the Collingwood Harbour Remedial Action Plan receives a certificate from former Commissioner Gordon Walker.

Commissioner Alice Chamberlin and Robert Tolpa, U.S. Environmental Protection Agency, Region V examine conditions at the Grand Calumet River/Indiana Harbor Canal Area of Concern.



6.1.1 Socio-Economic Considerations Related to Contaminated Sediments and Other Environmental Concerns in RAPS and LaMPS

Funding for RAPs and LaMPs will always be limited. Therefore, it is critical when developing RAPs and LaMPs to complete incremental and cost-effectiveness analyses. The former involves showing what gains stem from each additional allocation of resources to reduce beneficial use impairment and hence improve water quality, or conversely, what reductions in benefits result from reducing resources devoted to controlling the adverse impacts on beneficial uses. Examination of cost-effectiveness involves determining which actions will most improve beneficial uses per unit of resource input, i.e. which actions provide "the most bang for the buck" or where the most public good can be done for the least money.

Because funds are limited and will undoubtedly become more limited, it is also critical to establish priorities. Not all beneficial use impairments are necessarily of equal importance. Nor does control of all pollutants have the same urgency. Various criteria can be used to rank environmental stressors, as is being done with the "tiering" of pollutants in the development of LaMPs.

Management in RAPs or LaMPs is a continuous, adaptive process. It takes place in a dynamic context, in terms of : (a) changing demographic and economic conditions; (b) changing demands for outputs, reflecting changing social tastes; (c) changing ecosystems; and (d) changing weather patterns from year to year, and perhaps long-term with changing climatic conditions. A management strategy must take into account:

- the pattern of goods and services being produced
- a set of physical measures for producing the goods and services desired by society, e.g., improving water quality
- implementation incentives and systems that induce public and private activities to modify their behaviors
- institutional arrangements that allocate the tasks of management among public and private entities and link those entities
- financing the capital and operation, maintenance and replacement costs of management
- short-range and long-range data collection and research programs to reduce uncertainties in management factors.

Lakewide Management Plan Review Questions

In March 1995, the Commission conducted a workshop to gather input in the formulation of a series of questions to be used by Commission reviewers in evaluating Stage 1 and Stage 2 LaMPs, and in the evaluation of the designation of Critical Pollutants. These questions are listed below. Questions suitable for use in reviewing Stage 3 and Stage 4 LaMPs are under development.

6.1.2 Questions for Review of Critical Pollutant Designation

1. Have all substances known to occur in the lake and which meet one or more of the following criteria been designated as Critical Pollutants?

   Those that persist at levels that, singly or in synergistic or in additive combination, have caused, are causing, or are likely to cause impairment of beneficial uses due to:

   a. their presence in open lake waters
   b. their ability to cause or contribute to a failure to meet Agreement Objectives through their recognized threat to human health, wildlife and aquatic life
   c. their ability to bioaccumulate or biomagnify.

2. Considering the above criteria, does any evidence exist to support the designation of fewer or additional Critical Pollutants? If so, what change(s) should be made in the designation of Critical Pollutants and why should it (they) be made?

3. Did the state or provincial governments and the International Joint Commission cooperate in the designation of Critical Pollutants? What process was followed to consult with the public and what was the public's response?

6.2 LAKEWIDE MANAGEMENT PLAN REVIEW

6.2.1 Goals

To ensure that **Lakewide Management Plans** (LaMPs) at all stages embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in open lake waters. To ensure that ongoing or planned activities which may influence the chemical, physical and biological integrity of the waters of each lake are adequately described in the respective LaMP for that lake.

Specific Questions for Stage 1 LaMP Review:

1 a. Did the state or provincial governments and the International Joint Commission cooperate with the Parties in the designation of Critical Pollutants?

b. Do you agree with the designated Critical Pollutants? If not, what evidence do you have to support the revision of the designation or characterization of the Critical Pollutants?

c. How well defined is the threat to human health, wildlife or aquatic life, which is posed by the designated Critical Pollutants? Has the contribution of Critical Pollutants to the impairment of beneficial uses been defined?

2. Does the plan address the concerns which have been received from the interested or affected public?

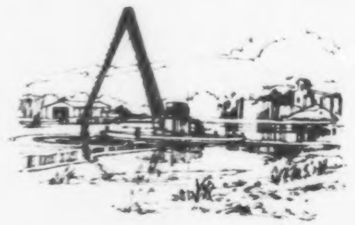
3. Has a process been established to address data gaps related to the defined threats and use impairments? Does the plan provide a mechanism to modify the classification of the existing Critical Pollutants if the data warrant?

4 a. Have the sources of Critical Pollutants been identified and all known loadings been quantified? If not, have the total loadings of Critical Pollutants been estimated by modelling or other methods? Has available information on the concentrations, sources and pathways of Critical Pollutants been evaluated? Are the data related to loadings sufficient to allow progress towards the Stage 2 LaMP?

b. Are there known pathways of Critical Pollutants for which inadequate loading information currently exists (e.g. air emissions from outside of the basin)?

5. Stressors other than Critical Pollutants may adversely influence the chemical, physical and biological integrity of the lake. If the document considers stressors other than Critical Pollutants, does it describe the contribution of these environmental stressors to the impairment of beneficial uses?

6. Did the LaMP incorporate pertinent socio-economic information?



Specific Questions for Stage 2 LaMP Review:

1 a. Do the goals for loading reductions of Critical Pollutants other than persistent toxic substances, if any, appear adequate to meet Agreement Objectives?

b. For Critical Pollutants considered to be persistent toxic substances as defined by the Great Lakes Water Quality Agreement, does the delineation of loading reductions appear to lead toward virtual elimination?

c. What interested or affected public was involved in determining the loading reduction goals in 1a and in 1b?

2. Are pathways of persistent toxic substances with sources outside of the basin identified?

3. Does the determination of LaMP activities, if any, to address the impacts of environmental stressors other than Critical Pollutants appear to be reasonable?

6.3 REFERENCES

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